AFIT/GOA/ENS/99M-10

AN EVALUATION AND COMPARISON OF THE ACE AND BRACE AIRFIELD MODELS

THESIS

David W. Williams, Major, USAF

AFIT/GOA/ENS/99M-10

DISCLAIMER STATEMENT

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

AFIT/GOA/ENS/99M-10

AN EVALUATION AND COMPARISON OF THE ACE AND BRACE AIRFIELD MODELS

THESIS

Presented to the Faculty of the Graduate School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operational Analysis

David W. Williams

Major, USAF

March 1999

AFIT/GOA/ENS/99M-10

AN EVALUATION AND COMPARISON OF THE ACE AND BRACE AIRFIELD MODELS

David W. Williams, B.S., M.S.
Major, USAF

Approved:

Kenneth W. Bauer Jr.
Chairman

5 MAR 99
date

James T. Moore

5 Mar 99
date

Acknowledgments

I would like to express my sincere appreciation to Dr. Kenneth Bauer, my research advisor, for his guidance, direction, and encouragement throughout the course of this thesis effort. His knowledge and experience were definitely appreciated. I would also like to thank my other committee member, Dr. James Moore, who provided valuable insight that contributed to the success of this endeavor.

I am also indebted to Major Robert Brigantic and Major Laura Suzuki at Headquarters, Air Mobility Command. They were always willing to answer any questions I had, and their continued willingness to give of their time was greatly appreciated.

David W. Williams

Table of Contents

List of Figures

Figure **Page**

List of Tables

Table **Page**

AFIT/GOA/ENS/99M-10

Abstract

Airfields are a critical aspect of our military's ability to project power or respond to crises throughout the world. It is crucial that mobility planners have an effective means to estimate the capacity of these airfields. The objective of this research is to examine common mobility metrics and evaluate existing means of measuring them. Currently, Air Mobility Command has two models, the Airfield Capacity Estimator (ACE) and the Base Resource and Capabilities Estimator (BRACE), that were designed to estimate the resource requirements and capacities of an airfield. This study offers a critical evaluation and comparison of the two models. Discrepancies of the models are highlighted, as well as possible improvements. Additional possible uses are also demonstrated, including a method in which the two models can be used together to enhance their overall results and increase the user's knowledge of an airfield's capabilities and limitations.

AN EVALUATION AND COMPARISON OF THE ACE AND BRACE AIRFIELD MODELS

Chapter 1

Introduction

Background

Strategic airlift is a crucial aspect of our nation's ability to achieve its foreign policy objectives. An integral part of this capability, along with the aircraft and the crews that fly them, are the airfields from which they operate. The capacity of the airfields used by the U.S. military have a significant impact on our overall capability to project power or to respond to a crisis worldwide.

The fact that our airfields have limited capacities has presented a challenge for air mobility planners. The amount of space and resources available at any airfield limits the number of aircraft that can be scheduled to deploy to, or flow through, that particular airfield. The ability of planners to estimate this capacity can sometimes be crucial to the success of an operation.

One of the primary methods for estimating airfield capacity in the past has been the use of a measurement called maximum on the ground (MOG). However, this term has been very difficult to define and has come to mean different things to different groups of people. The term in its most basic sense often refers to the maximum number of aircraft that can be physically parked at a particular airfield. Other definitions of MOG include the availability and capacity of other resources at the base, including the capability to conduct refueling, servicing, maintenance, cargo loading, and cargo

unloading operations. This is sometimes referred to as “working MOG”. The amount and availability of these types of resources affects the airfield’s ability to service arriving aircraft and prepare these aircraft for subsequent departure. It matters little that an airfield has sufficient parking for a hundred aircraft if it has only a single fuel truck or maintenance crew. Obviously, this airfield would be of little use to planners as an en route stop for deploying aircraft.

Two models have recently been developed to aid mobility planners in deriving airfield capacity estimates. The first of these is the Base Resource and Capabilities Estimator (BRACE). BRACE is a simulation model that was designed to aid in determining airfield throughput capacity and resource requirements. It does this by setting up queuing networks of the major processes that must occur at an airfield, including refueling, maintenance, and cargo loading and unloading operations.

The second model is the Airfield Capabilities Estimator (ACE). ACE is a spreadsheet model designed to estimate the daily capacity of an airfield based on available resources. It is a deterministic model that uses mathematical equations to calculate the expected amount of time each aircraft will require for each type of servicing, and then it uses this to compute an overall capacity of the airfield.

Research Objective

The ability to estimate MOG, airfield capacity, and throughput capacity is an important aspect of the overall mobility planning process. The objective of this research is to examine these mobility metrics and evaluate existing means of measuring them. First, the terms maximum on the ground (MOG), airfield capacity, and throughput are

studied in an effort to develop acceptable definitions for use by all parties involved in planning and executing mobility operations. Next, two existing models, ACE and BRACE, are evaluated to determine the capabilities and limitations of each model.

Scope and Limitations

The focus of this research is on strategic military airlift. MOG, airfield capacity, and throughput are analyzed in terms of mobility aircraft. Although other models may exist for estimating airfield capacity, this research focuses on the ACE and BRACE models.

Chapter 2

Definitions of Airfield Capacity Terms

One of the primary methods for estimating airfield capacity in the past has been the use of a measurement called maximum on the ground (MOG). However, this term has been very difficult to define, and it has come to mean different things to different groups of people. The term MOG is not defined in any current Air Force or Air Mobility Command (AMC) Instructions or Directives. However, a 1985 version of Military Airlift Command Regulation 55-28 defined MOG as "the highest number of aircraft being used in an operation which will be allowed on the ground during a given span of time based on simultaneous support" (Smith, 1985: 14). This definition is sufficiently vague to leave many questions unanswered and is of very little practical use.

The term MOG in its most basic sense often refers to the maximum number of aircraft that can be physically parked at a particular airfield. Even in this "basic" sense, the value varies greatly depending on the size of the aircraft in question. If you consider that the airfield parking will be used by several different types of aircraft of varying sizes, as is almost always the case, the task of deriving a MOG value that is of practical use for planning purposes is further complicated.

Other definitions of MOG include the availability and capacity of other resources at the base, including the capability to conduct refueling, servicing, maintenance, cargo loading, and cargo unloading operations. These definitions vary, and the way MOG is defined literally depends somewhat on the functional specialty of the individual in question. To an aircraft maintainer, MOG could be the maximum number of aircraft that

may require maintenance at one time, while to a fuel truck driver, it could represent the maximum number of aircraft that will require simultaneous refueling. To a transporter, MOG may express the maximum number of aircraft which will require loading or unloading at one time, while to a civil engineer, it could mean the maximum number of aircraft that can be parked on all ramp space at the airfield using power taxi operations (Smith, 1985: 14).

In a point paper written by Lt. Col. Dave Merrill, an analyst at HQ AMC/XPY, a much broader and more inclusive definition is given. Merrill defines MOG as "the maximum number of aircraft on the ground that can land, taxi-in, park, be unloaded, refueled, maintained, inspected, loaded, taxi-out, be cleared for departure, and takeoff" within each aircraft's planned ground time (Merrill, 1994: 1). This definition is also sometimes referred to as "working MOG". This particular definition of MOG is a function of six different major factors: aircraft type, airfield location, physical ramp space, planned aircraft ground times, logistics resource availability, and competition for limited resources (Merrill, 1994: 1). Each of these factors is defined more specifically in order to highlight the effects these factors have on MOG.

Many different types of mobility aircraft can be used simultaneously at a single airfield in any particular operation. Each of these different aircraft types has its own distinct "footprint" (size and weight) that affect the ramp space and load bearing capacity required for parking. They also have distinct maintenance requirements, material handling equipment (MHE) requirements, fuel capacity, and ground maneuverability. These factors combine to form a specific aircraft MOG.

The location and physical characteristics of an airfield also play an important role in determining MOG. Factors such as limited operating hours, Air Traffic Control (ATC) constraints, and political considerations all contribute to a location MOG. In addition, the size and shape of the ramp, its load bearing capability, taxiway widths, and obstructions on or near the ramp are some of the physical constraints that determine an airfield's physical MOG.

Planned aircraft ground time is another factor affecting MOG. The amount of time an aircraft is scheduled to spend on the ground depends on the purpose of the stop, and the events that must take place during the stop. For example, an aircraft that stops to off-load cargo, refuel, and obtain servicing and maintenance will obviously require a longer ground time than one that is stopping only to off-load cargo. If crew rest is also needed, the amount of planned ground time required increases substantially.

The availability of limited resources is probably the most common limiting factor affecting MOG values. These resources include fuel storage capacity, number of fuel trucks, fuel pump rates, number and location of hydrant systems, as well as the availability of maintenance personnel, aircraft spare parts, material handling equipment (MHE), power carts, light carts, oxygen carts, hangar space, and even billeting for the crews. The resource that most limits the throughput for each specific type of aircraft determines the logistics MOG for that aircraft type.

The final major aspect that determines MOG is the competition among various aircraft for resources and ramp space. When several aircraft have scheduled en route stops at the same airfield around the same time period, the demand for these resources is

obviously greater than it would be if only a few aircraft had scheduled stops. This affects MOG, particularly when the demand exceeds availability for any resource.

The overall MOG planning factor for each particular aircraft type at each particular location is generally determined from the most limiting of the factors listed above. This can obviously present problems to planners because many of these factors are continuously changing through time, especially during a wartime scenario (Merrill, 1994: 2).

Yet another derivative of the MOG concept used by some planners is smoothed MOG. Smoothed MOG introduces additional considerations in an attempt to "smooth the peaks in the air flow" (Morrison, 1996: 12). This further highlights the lack of one command-wide accepted definition.

Stucker and Berg of the RAND Corporation, in their report "Understanding Airfield Capacity for Airlift Operations" define MOG in very general terms, using definitions similar to those used above. However, their approach to analyzing the capabilities of an airfield basically ignores MOG and instead uses a measurement they call airfield capacity. They define airfield capacity as "the maximum number of missions that can be routed through and supported by a particular airfield during a 24-hour day, given specified resources" (Stucker, 1998: 2). Interestingly enough, if you remove the time factor from this definition, it appears very similar to a general definition of MOG.

Another measure of the capability of an airfield is cargo throughput. Throughput is a metric that is commonly used by Air Mobility Command. It is normally expressed as the amount of cargo that flows through a specific base, or theater, measured in tons per day, averaged over 30 days (Brigantic, 1999). An alternate definition of throughput is

"the maximum amount of cargo that can flow through an airfield in a day" (Rushing, 1997: 1-2). This latter definition is also sometimes referred to as throughput capacity. Throughput capacity is a function of the maximum amount of cargo each aircraft can carry, and the daily capacity of the airfield.

The above concepts can also be represented more formally, through mathematical equations. Parking MOG is simply the number of parking spots available that can accommodate the aircraft type in question, and can be represented as:

$$\text{Parking MOG} = P$$

where P represents the number of available parking spots for a particular type of aircraft. It must be kept in mind, however, that this P could vary for each different type of aircraft.

Working MOG and airfield capacity are a function of many variables and are much more difficult to quantify. If the assumption is made that all aircraft are on the same missions and thus have identical servicing requirements (fuel, cargo, maintenance, etc.), then airfield capacity can be defined as:

$$C = \text{Min}\ (R_i * A_i / S_i)\ \text{over}\ i = 1, \ldots, n$$

where C stands for the overall estimated capacity of the resources at the airfield (expressed in aircraft per day), R_i represents the quantity of a particular resource i available at the airfield, A_i represents the hours per day that resource i is available, and S_i stands for the time (in hours) required of the resource i in servicing one aircraft (Stucker, 1998: 8). From the equation, we can see that the capacity of the airfield is constrained by the most limited resource, in terms of resource availability and requirements.

Working MOG can then be defined as a function of airfield capacity as such:

$$\text{Working MOG} = C * T / H$$

where C represents the airfield's capacity (expressed in aircraft per day) as computed above, T represents the aircraft ground time (expressed in hours), and H represents the number of hours per day that the airfield is open (Plans: 20). As with the above equation for airfield capacity, this equation also assumes a single type of aircraft, with all aircraft having identical servicing requirements. If the constraining resource in the airfield capacity computation was the number of parking spots, then working MOG will be equivalent to parking MOG.

Cargo throughput capacity can also be expressed as a function of airfield capacity. The equation is:

$$\text{Throughput} = C * K$$

where throughput is expressed in cargo per day, C once again represents airfield capacity (expressed in aircraft per day), and K represents the maximum amount of cargo carried by each aircraft (expressed as cargo per aircraft). Once again, the assumption is made that all aircraft have identical servicing requirements.

<u>Airfield Capacity Calculations Example</u>

As an example, assume an airfield is open 24 hours a day, and has ramp space for ten C-17 aircraft, with each parking spot having an associated fuel pit. The following additional assumptions are made:

- There are two hydrant service vehicles
- Fueling is the constraining resource
- The airfield will process C-17 aircraft, each with a 2.25 hour standard ground time
- Each hydrant service vehicle requires one hour to refuel one aircraft
- Each aircraft can carry a maximum of 40 tons of cargo

Based on these assumptions, the following calculations can be made:

- Parking MOG = 10
- Airfield Capacity (C) = Min (R_i * A_i / S_i) over i = 1, …, n
  = 2 * 24 / 1 = 48 aircraft per day
- Working MOG = C * T / H
  = 48 * 2.25 / 24 = 4.5 aircraft
- Cargo Throughput Capacity = C * K
  = 48 * 40 = 1920 tons per day

<u>Chapter Summary</u>

Among the various definitions discussed for MOG, the one given by Mr. Merrill appears to be the most accurate for conveying a complete definition of working MOG as it pertains to mobility operations. His definition, that MOG is "the maximum number of aircraft on the ground that can land, taxi-in, park, be unloaded, refueled, maintained, inspected, loaded, taxi-out, be cleared for departure, and takeoff" within each aircraft's planned ground time appears to adequately summarize the many factors and operations that together determine MOG (Merrill, 1994: 1).

All of the same factors and operations that determine MOG must once again be considered when defining airfield capacity. The definition given by RAND, although technically correct, lacks the level of detail given in Mr. Merrill's MOG definition.

In analyzing the capabilities of an airfield for planning purposes, there is a danger in ignoring MOG and focusing solely on airfield capacity, as RAND does in their report. It may in fact be very beneficial to mobility planners to know that a particular airfield has the capacity to handle a certain number of aircraft in a 24-hour period. However, this tells us nothing about the number of aircraft that can be processed simultaneously, or in a short period of time. If mobility planners route too many aircraft through an airfield in a

short period of time, its capabilities may be exceeded, even though the number is well within the airfield's estimated daily capacity.

Chapter 3

Model Descriptions

Base Resource and Capabilities Estimator

BRACE, in the simplest of terms, is an analysis tool designed to estimate how much cargo can be processed at an airfield given some level of resources and under some aircraft arrival distribution. It is a queuing network simulation of the major processes that must occur.

BRACE was developed at the Center for Optimization and Semantic Control, Washington University, St. Louis. Program oversight and funding was provided by HQ AMC/XPY, Studies and Analysis. Program inception occurred during the mid-90's under the supervision of Capt Kim Schubert, with Travis Cusick as the developer at Washington University. The current version, 1.31, is dated 18 Dec 1997. BRACE was designed to aid in determining airfield throughput capacity and resource requirements. For a given set of resources, you can estimate the airfield's throughput capacity, or for a desired capacity, you can estimate the resources required. The goal, then, is to quantify the relationships between airfield resources, aircraft arrival streams or rates, ground times, maximum on ground (MOG), achievable throughput, and airfield efficiency.

To accomplish this, BRACE models the scheduled flow of aircraft at an airfield and simulates the aircraft's progression through major ground activities (cargo handling, refueling, and maintenance). In other words, BRACE is a discrete-event (aircraft arrival/departures), continuous parameter (time) simulation of a capacitated queuing

network (limited airfield resources). The 20000 lines of code were written in MODSIM II, and include animation of the process (Cusick, 1997: 1).

The figure below shows the conceptual model used in the simulation.

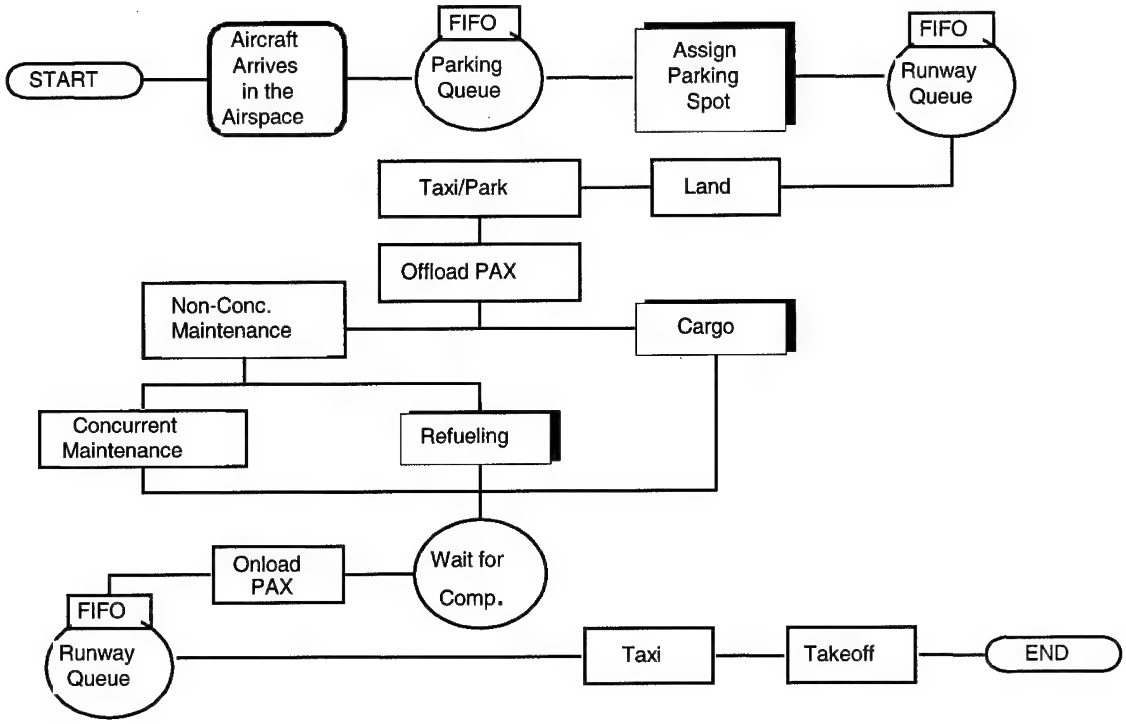


Figure 1. BRACE Activity Flow Chart (Cusick, 1998: 2)

Inputs to the model fall into four basic categories: aircraft arrival flow, payload profiles, airfield resources, and policy. The aircraft arrival flow may be an exponential, Erlang, or triangular arrival distribution of a user-specified proportion of C-130, C-17, C-5, C-141, KC-10, B-747, or DC-8 airframes. Alternately, the code allows the user to have an arrival process determined by an output file from MASS. Payload profiles are basically limited to tons per pallet and tons of rolling stock. The payload limits for each aircraft type are specified in a user-modifiable matrix.

Airfield resources indicate the ramp space allocation, the number and types of material handling equipment (MHE) available, and refueling equipment (trucks, hydrants, or both). In this category, the user can model a specific airfield by defining equipment assigned to a ramp, travel times to a ramp, and fuel pumping rates. Also, more than one ramp can be defined, and aircraft permissions at each ramp can be set. The user also designates the number of wide body only, narrow body only, and narrow body equivalent parking spots, as well as a narrow to wide body equivalence factor for the last type of parking spot. As an example, if a ramp has 20 narrow body equivalent parking spots, and the narrow to wide body equivalent factor is 2, then the ramp can accommodate 10 wide body, 20 narrow body, or an equivalent combination of aircraft.

The last category, policy, contains certain rules for the operation of the airfield. Here, the user can restrict the operating hours of the airfield, indicate how long an aircraft waits for ramp space before diverting, and how long a broken aircraft may occupy a parking spot before being removed from the field.

The results of the simulation are written to six output files that provide information applicable to each arriving aircraft, ramp usage (spots, hydrants, etc), material handling equipment usage, and summary data for each replication. These files include information on throughput, resource utilization, delays, activity times, and ground times. The figure at the top of the next page presents a graphical representation of the inputs and outputs to the BRACE model.

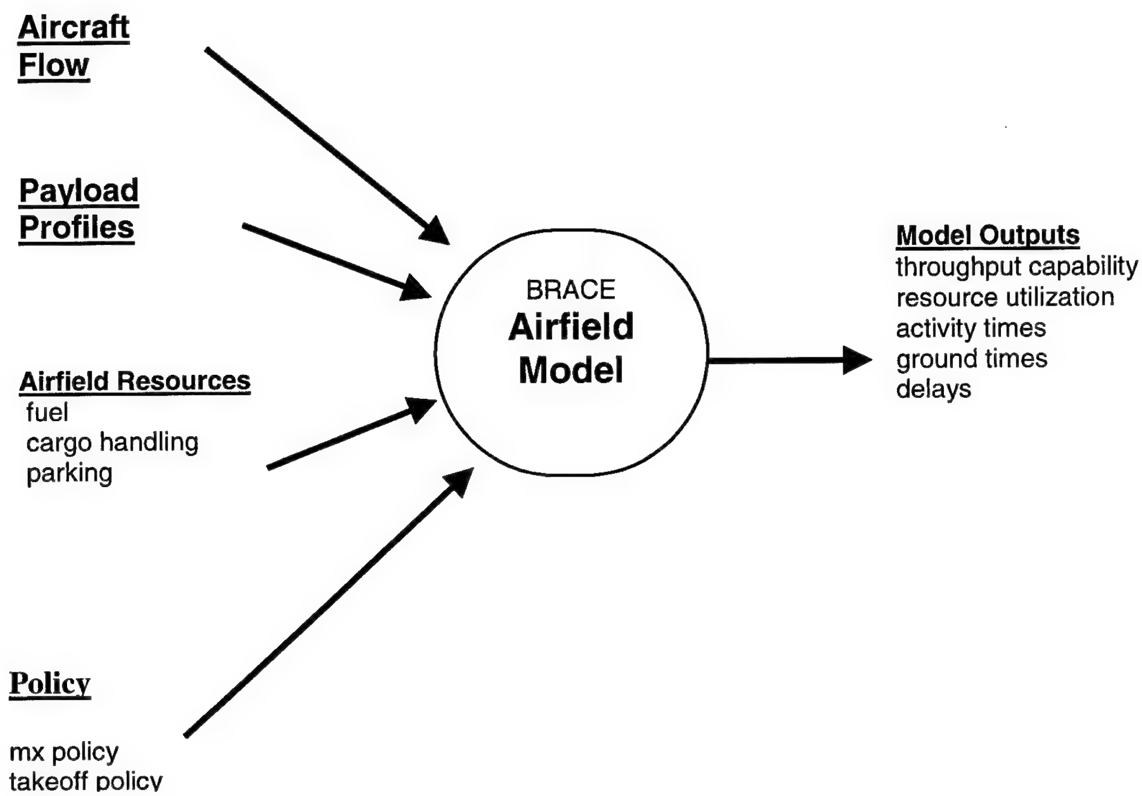


Figure 2: BRACE Inputs and Outputs (Schubert, 1996: 8)

BRACE is a stochastic model, but the variability is due to the aircraft arrival rate, the probability that an arriving aircraft is of a particular type, the probability that an arriving aircraft requires unscheduled maintenance, and the time required to accomplish the unscheduled maintenance (if required). All other times, including times for fueling, cargo processing, and scheduled maintenance, are deterministic, based on the type of aircraft and resources available.

Airfield Capacity Estimator

The Airfield Capacity Estimator (ACE) is a spreadsheet model designed to estimate the daily capacity of an airfield based on available resources. The ACE model was developed by James Stucker and Ruth Berg, at RAND's National Defense Research Institute. The research effort was sponsored by the U.S. Air Force and the Office of the Secretary of Defense (Stucker, 1998: i). The current version, ACE 97, was completed on 1 November, 1998, and was designed to be run on Microsoft Excel 97 (Stucker, November 1998: 1). Software for the model is available at no cost on the RAND home page at:

http://www.rand.org/publications/MR/MR700/ACE/ (Stucker, 1998: iii)

Inputs to ACE are numerous, and include airfield specific parameters, global parameters, and mission specifications. The airfield specific parameters include information on airfield layout (parking, hydrants, ports, etc.), and airfield specific aircraft servicing parameters, fueling parameters, and loading parameters. This includes inputs for the number and types of material handling equipment (MHE) available, fueling resources, and parking spots. The user inputs the number of each type of aircraft the ramp can accommodate, rather than the number of wide body and narrow body spots as in BRACE.

The global parameters include information on aircraft characteristics, aerospace-ground equipment, and global aircraft servicing times, loading parameters, and fuel parameters. Mission specifications include number and type of aircraft, aircraft configuration (cargo, passenger, or mixed), servicing profile (quick turn or full service), fuel required, and passengers and cargo to be on-loaded and/or off-loaded.

Outputs for ACE are rather limited, especially when compared to BRACE. They include average times for cargo loading/unloading and fuel transfer, average aircraft ground times, aircraft capacity used, and aircraft capacity remaining.

ACE offers the user the option to run the model in the expected-value mode, which is purely deterministic, or the Monte Carlo mode, which includes some random effects. However, even if the stochastic effects are included, they are very limited. The only variability included in the model is the probability that each aircraft requires repair, nitrogen servicing, oxygen servicing, and de-icing, and the time required to accomplish these activities (if required).

As alluded to earlier, the purpose of ACE is to determine the daily capacity of a particular airfield to support a variety of designated airlift missions with limited resources available. ACE accomplishes this through mathematical calculations within various spreadsheets. The user has the option to designate up to six different aircraft missions. All aircraft operating within a single mission must be of the same type and have identical mission specifications (fuel required, cargo on-loaded/off-loaded). The model evaluates the first mission first, with subsequent missions evaluated only if additional capability still remains (Stucker, 1998: 45).

While evaluating a mission, ACE first determines the average time required per aircraft for each required activity, including fuel transfer, cargo processing, and aircraft maintenance. Based on these times, an average aircraft ground time is also computed. Next, ACE uses these times to compute an average daily capacity for each resource, based on mission specifications and resource availability. This capacity is computed

separately for parking, aircraft servicing, loading, fueling, aircrew support, air-traffic control, and ground control.

The structure of the ACE model is shown in the figure below:

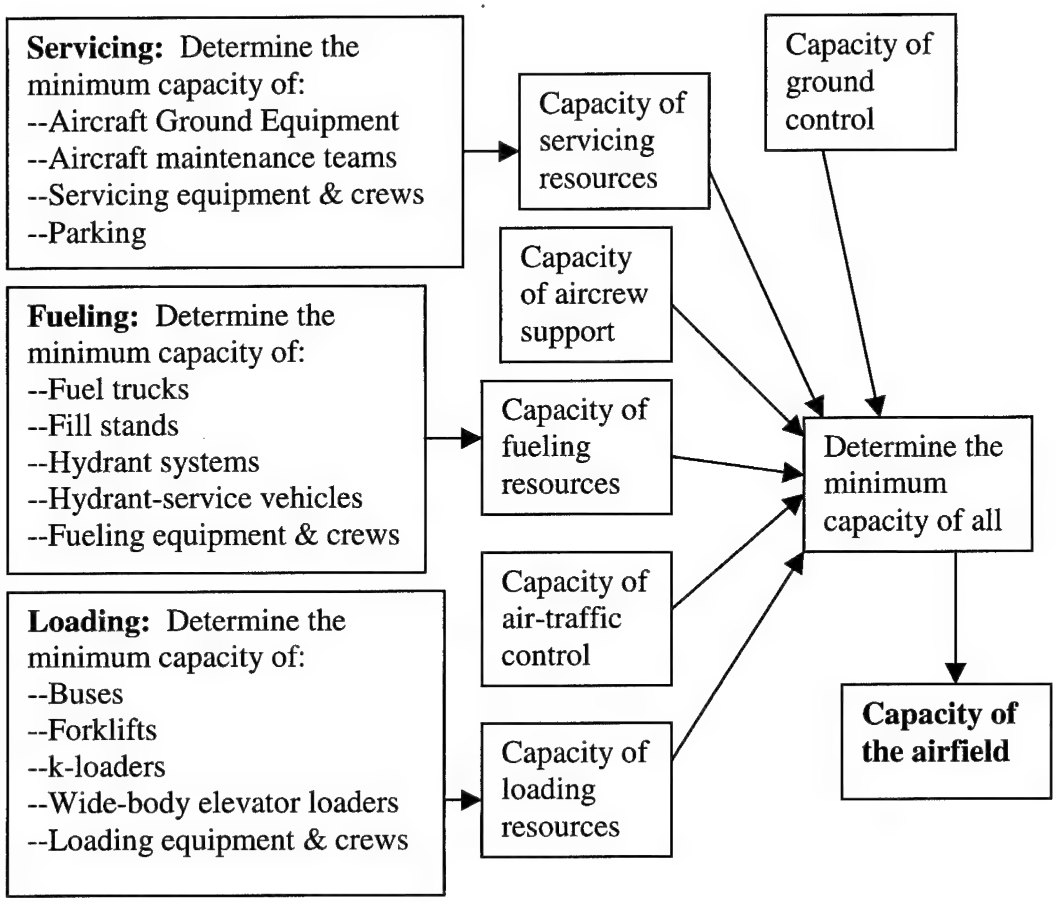


Figure 3: The Structure of the ACE Model (Stucker, 1998: 11)

As an example of a typical ACE calculation, suppose it takes a hydrant service vehicle one hour to fuel an aircraft. If the airfield has three hydrant service vehicles available, it can fuel three aircraft in an hour and 72 in a 24-hour period. Therefore, the daily capacity for fueling would be 72 aircraft.

The smallest of the resource capacities calculated is the airfield's overall capacity. If the number of aircraft required for that mission is greater than the airfield's overall daily capacity, then the mission cannot be supported. Assuming the mission can be supported, ACE next computes any remaining capacities. The number of aircraft required for the mission being evaluated is subtracted from each of the individual resource capacities to determine a capacity remaining for each resource. These remaining capacities are applied to the evaluation of the next mission, if one or more remain to be evaluated.

If the user inputs zero aircraft required for a mission, ACE will still compute the average times and capacities for each of the resources. However, all of the airfield's resource capacities will still be available to evaluate activity times and resource capacities for subsequent missions. Therefore, the user has the option of evaluating "and" or "or" missions. By specifying positive integers for the quantity of aircraft required for each mission, the user can determine the airfield capability to support several different missions concurrently. By specifying zero aircraft required, the user can determine the airfield's capacity for each of the missions individually (Stucker, 1998: 46).

Chapter 4

Problems and Limitations of the Models

BRACE Problems and Limitations

Currently, the BRACE model is not being used by any DOD office or agency for routine mobility analysis. Even HQ AMC/XPY Studies and Analysis, who funded and oversaw the development of the model, does not regularly use it. According to Major Brigantic, of the aforementioned office, the reasons for this are threefold. First of all, the analysis performed at HQ AMC/XPY usually does not focus on only one airfield, as BRACE does. Secondly, there are limitations to the model in terms of both its fidelity and its output data. And finally, according to Major Brigantic, the input parameters necessary to make the model produce realistic and credible results are often not available (Brigantic, 1998).

There are several problems and errors within the BRACE model that limit its usefulness for mobility analysis. First of all, the number of aircraft processed reported in the output files is not actually the number of aircraft processed, in terms of aircraft serviced, fueled, loaded/unloaded, etc. What BRACE reports as aircraft processed is actually aircraft arrivals, and includes all aircraft arrivals in the simulation, regardless of whether or not any servicing activity is performed on them. The number of aircraft actually processed must be computed manually by the user. This can be done by taking the total number of pallets off-loaded or on-loaded, as reported in the summary file for the simulation, and dividing it by the number of pallets carried by each aircraft, as defined by the user. The same can also be done by using total fuel on-loaded divided by

the amount of fuel on-loaded on each aircraft, as defined by the user. The number of aircraft fueled will always be the same as the number of aircraft that have had cargo on-loaded or off-loaded. The reason for this is that the BRACE simulation does not include the fuel and cargo numbers from each aircraft in the totals until that aircraft takes off. Therefore, an aircraft that has been fueled, serviced, and had cargo off-loaded will not be counted in the final output numbers if that aircraft has not yet taken off at the time the simulation terminates.

A second error in the program is that the delay time reported in the output files is not the actual aircraft delay time. The delay time in BRACE is computed by taking each aircraft's actual ground time in the simulation and subtracting the standard ground time for that type of aircraft as defined by the user. Therefore, regardless of the amount of time an aircraft spends waiting in queues for service, its reported delay time is based primarily on what the user defines as the standard ground time for that type of aircraft.

The delay time in the simulation can be computed, but it must be done individually for each aircraft. Even then, it is not a trivial matter. The aircraft often is delayed in a queue waiting for one service while another service is being performed. Since the simulation normally allows most services to be accomplished simultaneously, this results in an actual delay to the aircraft even though another service is being performed during the delay. However, this is not always the case. Suppose for example, that an aircraft needs to undergo extended maintenance. If the aircraft experiences a delay for a fuel truck, but the fueling is still completed before the maintenance is done, then the aircraft would have experienced no real delay to its subsequent departure by waiting for the fuel truck. It all depends on how the user chooses to define a delay.

One of the most serious errors of the BRACE simulation occurs in the manner in which diverted aircraft are handled. When aircraft divert, they are recorded in the output files as having had the scheduled cargo on-loaded or off-loaded, and the scheduled fuel on-loaded. Obviously, this results in total cargo and fuel statistics that are artificially high. In addition to this, when the number of aircraft serviced is computed as discussed earlier, the diverted aircraft are included in the resulting number of aircraft serviced. In order to arrive at accurate numbers for aircraft serviced, total fuel on-loaded, and cargo processed, the totals from the diverted aircraft must be subtracted.

Another problem with the BRACE model is that the simulation does not terminate at the directed time. Instead, it stops aircraft arrivals at that time, but then finishes processing all aircraft in the system before the simulation terminates. This results in erroneous results for most of the summary outputs if results are desired for a fixed period of time, as is usually the case. To terminate BRACE at a particular time, the user must manually abort the simulation at the desired time. This requires the user to physically watch the simulation clock included in the program animation, and select "abort the simulation" at the desired time. This also precludes the user from taking advantage of BRACE's ability to run several repetitions consecutively.

The next problem in BRACE is the way in which forklifts are modeled. According to the BRACE user's manual, forklifts are required to move cargo between the loading docks and the cargo marshaling area (Cusick, 1997: 7). One would expect that, without forklifts, the cargo processing operation would be greatly hindered, and eventually grind to a halt. However, when forklifts are removed from the system in a simulation run, the actual change in the output is negligible.

Still another error in the BRACE model is the way in which the resource utilization is computed for wide body only parking spots. The results reported for this are extremely high, almost always greater than the actual number of parking spots. The number increases each day the simulation is run, although it does not appear that anything useful is actually being measured. The resource utilizations computed for narrow body only and narrow body equivalent parking spots appear to be correct, however. If utilizations for wide body parking spots are desired, narrow body equivalent parking spots can be substituted for these. If both narrow body and wide body aircraft are used in the simulation, these spots can be assigned to a separate ramp that is restricted to only wide-body type aircraft.

In addition to the many problems and errors in BRACE, it also has many other limitations. First of all, the program requires a long period of time to run. Even when the animation is turned off, it surprisingly appears to have little or no effect in the speed of the simulation. And since the program must normally be monitored and aborted manually, this places a significant burden on the user in terms of required time.

Another limitation results from the fact that BRACE is primarily a deterministic model. As discussed earlier, the only stochastic inputs are aircraft mean inter-arrival time and unscheduled repair times. The deterministic service times, although reasonable approximations, do not accurately model the real world, where uncertainty is the norm. Another unrealistic assumption is that nearly all service activities, with the exception of one category of scheduled maintenance, are permitted to be conducted simultaneously. In actual airfield operations, fueling is almost always isolated, with no other service activities performed until the fueling operations are complete. And even in a crisis or

contingency operation, when simultaneous fueling might be permitted, there are still many unscheduled maintenance operations that could not be conducted while fueling and/or cargo operations are taking place. BRACE does not provide the capability to model these.

Still another limitation of BRACE is that hydrant-service vehicles are not modeled. While the program models fuel hydrants, it does not model the vehicles required to pump the fuel from the hydrant to the aircraft. This makes the implied assumption that if a parking spot with a fuel hydrant is available, the aircraft can automatically refuel from the hydrant. Although a seemingly minor omission, this does limit the scope and type of studies that can be accomplished with BRACE, and further limits the detail in which an actual airfield can be modeled.

Although hydrant fueling can still be modeled, the only resource involved is the number of parking spots with hydrants. This creates problems when trying to limit the resource, unless fuel trucks are also included. When no fuel trucks are included, the only useable parking spots are those with fuel hydrants. Even worse, aircraft in the simulation will continue to park on the spots without hydrants. Since they have no way of being fueled, they remain parked there for the duration of the simulation.

A final limitation of BRACE is that it gives no direct results for airfield capacity or MOG. It is possible, however, to compute these values. It is very simple to compute parking MOG only, because the user defines the number of wide body, narrow body, and narrow body equivalent parking spots, and parking MOG would simply be equal to the number of parking spots that can accommodate the type of aircraft in question. However,

computing working MOG and airfield capacity is much more complex. This will be discussed in more detail in the next chapter.

ACE Problems and Limitations

ACE, like BRACE, is currently not being used by any DOD office or agency for routine mobility analysis. The reasons ACE is not used are the same as those cited by Brigantic in the previous section for BRACE not being used along with a few additional ones to be discussed below.

The first problem noted with ACE was that the previous version of the model was designed to run on an earlier version of Microsoft Excel, and did not work with Excel 97. James Stucker, the primary developer of the ACE model, was notified of this discrepancy, and within a few weeks a new version of the model, ACE 97, had been developed that was compatible with Excel 97.

Undoubtedly, the most significant problem with ACE is the manner in which it models fueling operations. The ACE model contains two different types of fueling resources: fuel trucks and hydrant-service vehicles (HSVs). It also has a means of representing fuel pits, with a user input number of aircraft allowed to refuel from hydrants at once. The biggest problem is the failure of ACE to accurately model fuel trucks. Although ACE includes fuel trucks in the model, in reality it does nothing with them. The number of fuel trucks used makes no difference to the average amount of time required to fuel an aircraft or to the airfield's capacity for fueling operations.

If the number of HSVs, fuel trucks, and fuel pits (number of aircraft that can be serviced by hydrants at once) are all set to zero, then the fuel time and fuel capacity

computed by ACE are both zero, as they should be. If however, the number of fuel trucks is increased to *any* number greater than zero, ACE computes an average fuel transfer time per aircraft, but the airfield capacity for fueling operations is still zero. This indicates that ACE is not allowing fueling to be conducted with fuel trucks. This was confirmed with additional runs with varying degrees of fueling resources.

If zero HSVs are entered for a run, but the number of fuel pits is any number greater than zero, then the time required for fueling operations computed by ACE is zero, but the fuel capacity is set equal to a maximum value for fuel capacity. This maximum value is computed based on other inputs under the heading of "Aggregate Fuel Resources". In this case, the number of fuel trucks input makes no difference, even if it is zero. So, basically, with zero fuel trucks and zero HSVs, the model reports that our capacity for fueling is at the maximum value it can be, even though we have no fueling resources.

If the number of HSVs and fuel pits are both greater than zero, then ACE computes seemingly "correct" values for average fueling time and fueling capacity based on hydrant fueling. However, once again these values are completely independent of the number of fuel trucks used in the run. Also, the fueling capacity cannot exceed the maximum value for fuel capacity, as discussed previously.

Another error in ACE occurs in its default data. ACE has a substantial amount of data pre-loaded, in both the airfield parameters and global parameters sections. This includes availability times, in minutes per day, for the fueling and loading equipment. The rationale here is that every piece of equipment is only available for use a certain percentage of the time due to equipment malfunctions and breakdowns. The availability

times, in minutes per day, included in the default parameters of the ACE model are 115 minutes for the 25-k loaders and wide-body elevator loaders, 141 minutes for the 40-k loaders, and 172 minutes for the forklifts.

According to Major Laura Suzuki, of HQ AMC/XPY, these values used by RAND in the ACE model are extremely inaccurate, and "should never have been used in the way they were being used" (Suzuki, 1998). The numbers used were actually reported as average engine-on hours per k-loader during peacetime use. Since we have many more loaders than we actually need for peacetime operations, these times are well below the maximum time the loaders could have been used. The actual availability rate for the 40-k loader, for example, is approximately 0.72, according to Major Suzuki (Suzuki, 1998). This corresponds to an availability time of 1036 minutes per day, compared to the 141 minutes used by RAND.

This problem, in theory, is a relatively simple one to correct. Inputting the correct data does not appear to be a problem, since the user can easily change all of the input parameters. However, this assumes that the correct data is available to the user. Since the data pre-loaded in the model cannot be relied on, this greatly increases the burden on the user to obtain reliable data. Since the model contains 27 pages filled with hundreds of input parameters, this burden will most likely prove to be a substantial one.

Aside from its problems in modeling fueling operations and data reliability, the ACE model also has several other limitations. First of all, every aircraft within each mission must have identical input parameters, including aircraft type, configuration, amount of fuel required, and number of passengers and pallets to be off-loaded and on-loaded. Secondly, only six different mission types can be entered, and ACE evaluates

each mission individually before proceeding to the next mission. These two limitations combined significantly reduce the model's potential as a mobility planning tool and they are additional reasons cited by Brigantic why the model is currently not being used (Brigantic, 1998).

Another limitation of ACE is that it is primarily a deterministic, mathematical model, with little or no stochastic inputs. In the expected-value mode, it is entirely deterministic. Even in its Monte Carlo mode, the only stochastic inputs permitted are repair times, de-icing times, and oxygen and nitrogen servicing times. Because computations are based on strict mathematical equations, it appears that ACE's airfield capacity estimates may be a little on the optimistic side in most cases. They may more adequately represent a best-case maximum limit on airfield capacity, rather than an estimate of the true capacity of the airfield.

Chapter 5

ACE and BRACE: Additional Possibilities and Uses

Using ACE and BRACE Together

It is possible to use the BRACE and ACE models in conjunction with one another to improve the results output by each. Comparing the results of one model with the other can validate the results of both models. In doing so, additional knowledge and insight of the airfield's true capacity, as well as their actual limiting factors, can be gained.

With a few exceptions, it is possible to enter comparable input parameters in ACE and BRACE, allowing the number and availability of resources and parking spots to be identical in both models. However, presently both models contain errors, resulting in difficulties in equating the fueling resources of the two models.

As discussed earlier, ACE does not correctly utilize the fuel trucks in the model. Therefore, hydrant-service vehicles (HSVs) must be used as the fueling resource in ACE. BRACE, on the other hand, does not model HSVs. Although BRACE does have the capability to model fuel hydrants, without HSVs it presents difficulties in the modeling of hydrant fueling as a limited resource. If fuel trucks are not included in the model, then every parking spot must have a fuel hydrant in order to be useable for fueling aircraft. Therefore, if fueling is to be modeled as a limited resource, it must be done with fuel trucks.

As a result, it is nearly impossible to equate the fuel resources of the two models. This creates problems when we are attempting to enter comparable input parameters in

both models to compare differences in the results. There are two possible approaches to address this problem, although neither is ideal.

The first approach is to attempt to equate fuel trucks in BRACE to HSVs in ACE. If the amount of fuel required by each aircraft is less than or equal to the amount carried by a fuel truck, then each HSV in ACE could be matched with one fuel truck in BRACE. However, this is rarely the case, since it will normally take many fuel trucks to completely fuel a large mobility aircraft. For example, a C-5 aircraft requiring 45,000 gallons of fuel would need eight large (R-11) fuel trucks or ten small (R-9) fuel trucks to completely fuel. Meanwhile, the same aircraft would need only one R-12 hydrant service vehicle, since the vehicle pumps fuel from a hydrant to the aircraft.

However, this does not mean that we should equate each HSV in ACE with eight fuel trucks in BRACE. The C-5 aircraft will use only one fuel truck at a time, and each fuel truck will travel to a fuel fill stand to get refilled as soon as it has finished fueling the aircraft. Watching the simulation in the BRACE model and examining the results, it appears that two fuel trucks in the model can provide a near continuous flow of fuel to an aircraft. While the first one is delivering its fuel to the aircraft, the second fuel truck travels to the fuel fill stand and returns with a full fuel load to relieve the first.

The second option for handling the differences in fueling resources between the two models is to ignore the fueling resources altogether. If we are not concerned about the effect the fueling resources have on constraining the capacity of the airfield, we can set the level of the fuel resources artificially high to ensure they are not a limiting factor. This effectively removes the fuel resource from the overall airfield capacity equation, and allows us to focus on how the other resources affect the capacity.

Determining Airfield Capacity in BRACE

As mentioned in the previous chapter, BRACE does not include a direct measure of airfield capacity as an output result. However, it is possible to determine airfield capacity indirectly. To do so, the simulation must be run with an aircraft arrival rate that saturates the airfield and results in it operating at its optimum efficiency. The arrival rate must result in the maximum number of aircraft possible being processed per day.

The ACE model can be used to come up with an approximation of this arrival rate. First, the user must ensure that comparable input parameters are entered for both models. The ACE model can then be run to determine the best-case daily capacity of the airfield for a specific type of aircraft using predetermined servicing requirements. This daily capacity can be converted to a mean interarrival time for use in BRACE in the following manner:

Mean Interarrival Time (minutes) = 1440 minutes per day / ACE average daily capacity

The aircraft arrival stream in BRACE can be modeled using the exponential distribution, since the exponential adequately models true random arrival streams and requires only one parameter, the mean. Using the mean interarrival time computed from the equation above allows us to run BRACE with an aircraft arrival rate at the level of the airfield's maximum capacity as determined by ACE.

Next, we can determine the average daily airfield capacity in the BRACE run. This is done by dividing the total number of aircraft serviced by the number of days of the simulation run. If nearly every aircraft was processed in the BRACE run, the average daily capacity as determined by BRACE should be relatively close to that determined by ACE. However, the BRACE capacity for this initial run will always be

less than or equal to the ACE capacity, since the arrival rate in BRACE was determined by the ACE capacity, and it is impossible to service more aircraft than arrive.

The previous computation results in an average daily airfield capacity for the aircraft arrival rate that was used. However, this may or may not be the airfield's maximum daily capacity. Additional BRACE runs are needed for confirmation. First, though, the resource utilizations in the BRACE output files should be checked. If the utilizations of all resources (k-loaders, fuel trucks, and parking spots) are below 100% (the utilization of the resource is less than the number of resources available as input to the model), then the computed daily capacity is almost assuredly below the maximum obtainable daily capacity. In this case, additional BRACE runs will need to be made while increasing the aircraft arrival rate (by decreasing the aircraft mean interarrival time), until the resource utilization of the constraining resource approaches 100% and the number of aircraft serviced plateaus at a maximum value.

If the utilization of one or more resources is at or very near 100%, then this is our constraining resource, or resources. In this case, increasing the arrival rate will not increase the number of aircraft serviced and thus not increase the average daily capacity. However, if the airfield is over saturated by arrivals, the number of aircraft serviced in BRACE may actually decrease. Therefore, to determine if we are at the absolute maximum capacity, additional BRACE runs should be made while decreasing the aircraft arrival rate until the utilization of the constraining resource drops below 100%.

The processes described above for determining the maximum airfield capacity in BRACE are summarized in a flow chart on the following page.

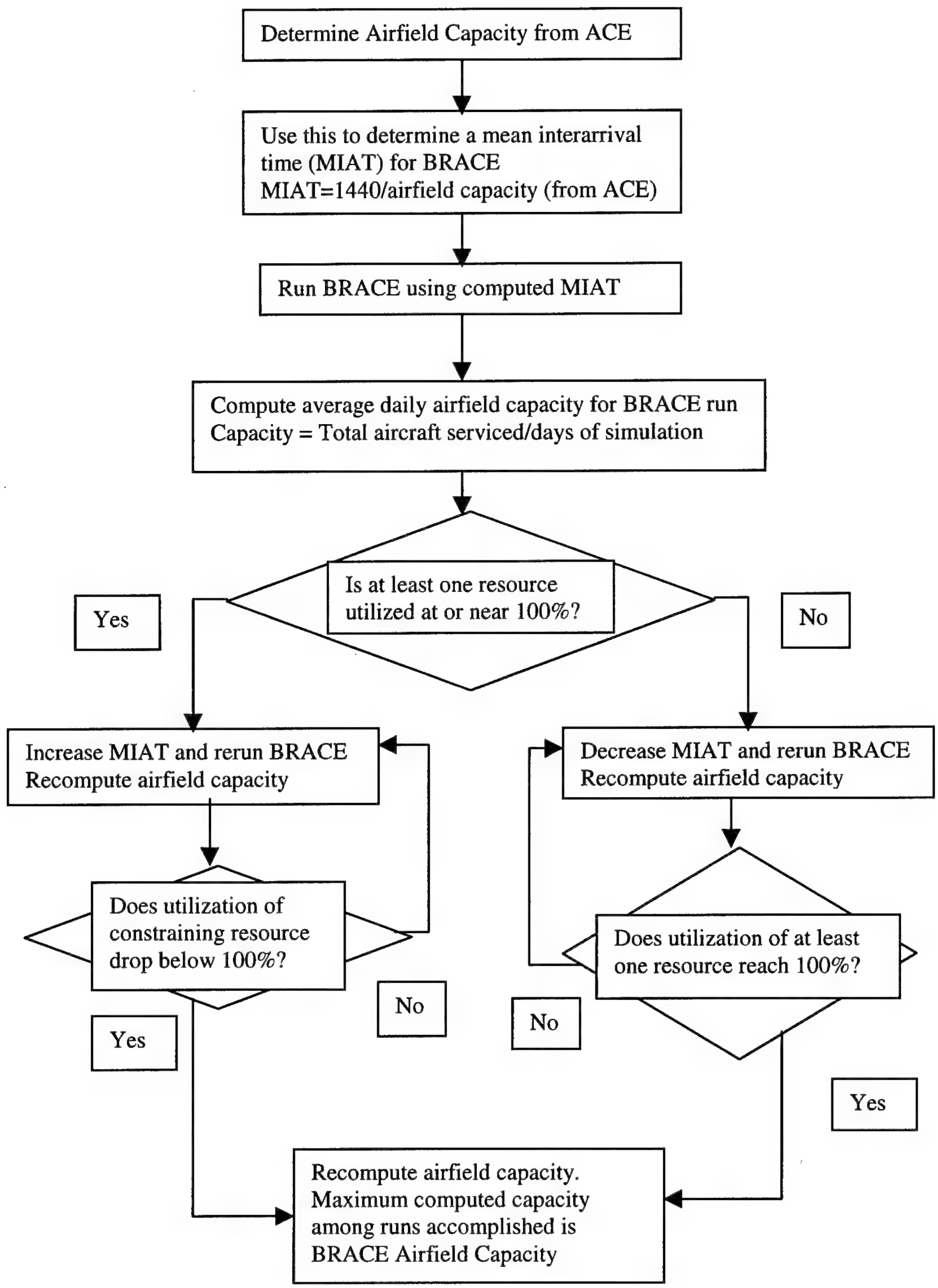


Figure 4: BRACE Airfield Capacity Estimation Process

If ACE and BRACE are truly measuring similar things, and estimating airfield capacity in compatible manners, then the constraining resource in each model should be the same, and the computed airfield capacity of each model should be relatively close to that of the other. In practice, however, the BRACE capacity will usually be lower, often times significantly so. This is primarily due to the fact that in the ACE model, there is no queuing and every aircraft gets serviced. The capacity is computed using mathematical equations, which in reality only establishes a best-case upper bound on the actual airfield capacity. In BRACE, on the other hand, we are deliberately saturating the system and operating at the limiting capacity of the constraining resource, so substantial queuing is to be expected. Since at the end of the BRACE run, there are still many aircraft waiting in queues that have not yet been serviced, it is not surprising that the average number of aircraft serviced per day in BRACE should be lower than the average number serviced in ACE.

This same inconsistency between the two models is also evident when looking at the average aircraft system times. The system time in ACE represents the no-waiting service time for the aircraft, while the system time in BRACE includes queuing times. These queuing times can often be much greater than the service times, especially when we are intentionally saturating the system.

<u>BRACE Example 1:</u>

As an example, the ACE model was run using a single ramp with 12 parking spots (all with fuel hydrants), two hydrant-service vehicles, and two 60k-loaders. All resources were assumed to be available 100% of the time. C-17s carrying 18 pallets each and

requiring 150,000 pounds of fuel (about 22,400 gallons) were used. According to the ACE model, the daily aircraft capacity for the airfield in question was 31, and the limiting resource was the k-loaders.

This number was then used to determine an interarrival time for use in the BRACE model. Dividing 1440 minutes per day by 31 aircraft per day, a mean inter-arrival time of 46.45 minutes is obtained. This interarrival time was input into BRACE, along with the other comparable input parameters used in the ACE run. Four large (R-11) fuel trucks were used to approximate the capacity of the two HSV's used in ACE. The BRACE simulation was run for twelve days, with the statistics cleared after the second day, resulting in a ten-day period in which statistics are gathered. If our airfield simulation was running at peak capacity with k-loaders as the constraining resource, as determined by ACE, we would expect a k-loader utilization very near the resource availability of two. The resulting output k-loader utilization was that, at 2.0. The ramp utilization was also high, at 11.82, but this was due to the aircraft waiting for k-loaders, and not a shortage of parking spots. In fact, if the simulation is rerun using the same input parameters but half the number of parking spots, the average capacity remains the same. The fuel truck utilization was 2.4, well below the resource availability of 4.0. The number of aircraft serviced in a ten-day run was 250, for an average of 25.0 per day.

Next, the aircraft mean interarrival time was increased to 50 minutes, and the simulation rerun. The k-loader utilization remained at 2.0, and the average capacity increased slightly, to 25.1. When a 55 minute interarrival time was used, the results were a k-loader utilization of 1.98 and an average capacity of 24.9. At 60 minutes, the results finally decreased noticeably, to a k-loader utilization of 1.91 and an average capacity of

23.7. So, the maximum average daily capacity as determined by BRACE appears to be 25.1, a little below the ACE determined capacity of 31. However, trying alternate arrival rates with mean interarrival times between 50 and 55 could yield a capacity slightly greater than 25.1.

The results are summarized in the table below.

Table 1: Example 1 Results

Mean Interarrival time (minutes)	Airfield Capacity	K-loader Utilization
46.45	25.0	2.0
50.0	25.1	2.0
55.0	24.9	1.98
60.0	23.7	1.91

It may seem a waste of time to do the additional runs when the average capacity increased by a mere 0.1. However, with different sets of input parameters, the increase in capacity is often significant when the arrival rate is decreased. An alternate approach of keeping the airfield from becoming overly saturated is to limit the number of aircraft holding and waiting to land. This can be done be allowing aircraft to divert if the delay before landing exceeds a certain specified time.

According to ACE, the average aircraft system time for this scenario is 2.867 hours. When we examine the BRACE output, we see an average system time of 23.98 hours. This vast disparity in system times is due primarily to the queuing in the BRACE model, as discussed earlier. In fact, the vast majority of the system time was due to the aircraft holding prior to landing when no parking spots were available. If this delay time is limited by allowing for diverts, the average system time drops considerably.

BRACE Example 2:

As another example, the ACE model was run using a single ramp with 12 parking spots (all with fuel hydrants), four hydrant-service vehicles, and six 60k-loaders. Once again, C-17s carrying 18 pallets each and requiring 150,000 pounds of fuel (about 22,400 gallons) were used. According to the ACE model, the daily aircraft capacity for the airfield in question was 72, and the limiting resource was the k-loaders.

This number resulted in an interarrival time of 20 minutes for use in the BRACE model. When BRACE was run using this arrival rate (and eight fuel trucks to equate to the four HSVs), the average capacity was 37.1 aircraft per day. In this case, the limiting resource was the fuel trucks, with a utilization of 8.0 (100%). The k-loader utilization was 4.7.

When the same scenario was run allowing aircraft to divert after a 60 minute delay, the average capacity jumped to 41.8. The fuel truck utilization and k-loader utilization remained the same, at 8.0 and 4.7 respectively.

The same increase in average capacity can also be observed by varying the aircraft interarrival time. This scenario was run several times while varying the interarrival time in order to determine the actual maximum airfield capacity for BRACE. The results are summarized in the table on the top of the next page.

As can be seen from the table, the maximum airfield capacity for the given set of resources is 42.3, and occurs with a mean interarrival time of 33.5 minutes. It is also interesting to note that the maximum capacity occurs at the point where the utilization of the constraining resource has decreased below 100%. This is normally the case.

Table 2: Example 2 Results

Mean Interarrival Time (minutes)	Airfield Capacity	Fuel Truck Utilization
20	37.1	8.0
20 (with divert after 60 min delay)	41.8	8.0
25	39.6	8.0
30	41.4	8.0
32	42.0	8.0
33	42.1	7.86
33.5	42.3	7.27
34	41.6	6.4
35	40.7	5.51

As mentioned previously, it is possible to use aircraft diverts to prevent the airfield from becoming overly saturated. It is normally effective to use a divert time of approximately three times the mean interarrival time. Through this method, the user can often obtain a reasonably close approximation to BRACE's maximum capacity without conducting multiple runs. As can be seen, the airfield capacity obtained through this method was 41.8, reasonably close to the actual maximum capacity of 42.3. However, there is no guarantee that the result obtained through this method will be as close to the maximum airfield capacity as that seen in this example. Furthermore, by varying the time until divert, the airfield capacity obtained will also vary.

Apparent BRACE Anomalies

The difficulties encountered in computing an airfield capacity for BRACE are primarily due to the manner in which BRACE handles airfield saturation. As discussed previously, if the arrival rate in BRACE is increased beyond the point where the utilization of the constraining resource is near 100%, then the number of aircraft

processed in the simulation actually decreases. This appears counterintuitive for a queuing model like BRACE.

When no diverts are allowed and the airfield is saturated with arrivals, the longest waiting times occur in the holding pattern queue, where aircraft wait for a parking spot when none are available. From simple queuing theory, assuming there are always customers available to be served, then the number of customers served in any period of time is equal to $\mu * t$, where μ is the rate at which customers are served, and t is the length of time in question (Ross, 1997: 419). The number of customers served is completely independent of the length of the queue or the amount of time customers spend waiting in the queue. As long as there is continually at least one aircraft in the holding pattern queue, it should make no difference to the operation of service activities on the airfield whether there are one or one hundred aircraft waiting. The length of the holding pattern queue should be transparent to the servers on the ground, and should have no effect on the number of aircraft that can be serviced.

However, the length of time aircraft wait in the holding queue does affect the number of aircraft that are processed in the BRACE model. Although this could be looked on as an error when the model is viewed as a queuing network, it does in fact contribute to the realism of the simulation. With an actual real-world airfield, it is very likely that the number of aircraft processed would decrease when the airfield is flooded with arrivals. In fact, Merrill and Szabo addressed this very phenomenon in a presentation for the 62nd Military Operations Research Society Symposium entitled "The Mobility Paradox." In it, they state that "the coordination of limited fueling, maintenance, loading, and manpower assets to maximize throughput depends upon a

limited number of aircraft per day. Adding aircraft can magnify delays experienced for all users and throughput to a theater can and does decrease as the number of aircraft increases" (Merrill and Szabo: 4). It is not clear, however, whether or not the decrease observed in BRACE was actually intended by the model developer.

The output results from BRACE example two above were examined in an attempt to discover the cause of this apparent anomaly. In this example, it appears that the decrease in airfield capacity that occurred as the aircraft arrival rate increased was due to two factors, an increase in the delay time waiting for fuel trucks and an increase in unscheduled maintenance times.

This brings up another interesting observation about BRACE. Although the same random number seeds were used for each of the runs in example two, the unscheduled maintenance times assigned to the individual aircraft are different for each of the runs. According to the BRACE users manual, the maintenance times are assigned based on empirical distributions from the GO-81 information system, which collects data on aircraft breaks. The time to fix an aircraft is assigned to one of seven time categories: 0-4 hours, 4-8 hours, 8-12 hours, 12-16 hours, 16-24 hours, 25-48 hours, and 48-72 hours. BRACE then assigns repair times distributed uniformly within each time group (Cusick, 1997: 4).

What is not clear is the manner in which these times are assigned to individual aircraft. If two runs are made using identical input parameters and the same random number seeds, the repair times assigned to each aircraft are the same. However, if any input parameter is changed, the repair times change, even though the same random number seeds are used. Even more interesting, when the delay time in holding increases,

the average time of unscheduled maintenance also appears to increase, in general. In a real world situation, it does make sense that aircraft that are in the air for longer periods of time due to holding delays might experience more unscheduled maintenance. Once again, however, it is not evident whether or not the developer intended the model to operate in this manner.

A second apparent anomaly in the BRACE model can be detected by examining the output results in Appendix B. Occasionally, when the availability of a particular resource increases, with all other input parameters remaining the same, the capacity of the airfield actually decreases. An example of this can be seen in the results for the C-5 aircraft. With twelve parking spots, four fuel trucks, and six 60 k-loaders available, the resulting airfield capacity was 21.0. However, when the number of fuel trucks was increased to eight, with all other inputs remaining the same, the airfield capacity actually decreased to 20.8.

Although this appears to be an error in the program, it is due to the same effect observed above. The unscheduled maintenance times for the two runs are different, and the larger maintenance times for the second run result in a decrease in the capacity of the airfield. Once again, it is not clear why the maintenance times are greater for the second run, but it may be attributable to random effect.

Determining Working MOG in ACE and BRACE

It is also possible to use ACE and BRACE to compute values for working MOG. As mentioned previously, working MOG can be defined as a function of airfield capacity

as shown in the following equation:

$$\text{Working MOG} = C * T / H$$

where C represents the airfield's capacity (expressed in aircraft per day) as computed above, T represents the aircraft ground time (expressed in hours), and H represents the number of hours per day that the airfield is open (Plans: 20). In ACE, the program output includes both airfield capacity and average aircraft ground time, so the working MOG value can be computed directly.

In BRACE, however, it is more difficult. First of all, airfield capacity must be computed, as described above, by saturating the airfield with arrivals. This creates a problem, though, because the substantial queuing results in excessive ground times. Recalling the definition of working MOG from Chapter Two, Merrill states that working MOG is "the maximum number of aircraft on the ground that can land, taxi-in, park, be unloaded, refueled, maintained, inspected, loaded, taxi-out, be cleared for departure, and takeoff" within each aircraft's planned ground time. (Merrill, 1994: 1) For the equation to adhere to this definition, the ground time used must be within that aircraft's desired planned ground time.

To obtain a conservative estimate for working MOG, the user can use the model's standard no-queue aircraft ground time. This can be obtained by running the BRACE model with a very low aircraft arrival rate, where a minimum amount of queuing occurs, and determining the average aircraft ground time in this condition. BRACE, however, does not include an average ground time in any of its output files. It does give a ground time for each individual aircraft in the aircraft.out file. To compute the average, these

files can be imported into a spreadsheet, and the individual ground times of each aircraft can be averaged.

As another option for the working MOG calculation, the user can use a standard aircraft ground time for the aircraft type in question. A third option would be to use an average aircraft ground time obtained from the ACE model. However, if either of these times are used, the BRACE run with minimum queuing as described above should still be conducted, to ensure that aircraft in the BRACE model can be serviced within the time period being used.

Using ACE and BRACE to Validate a Larger Scale Model

The ACE and BRACE models can also be used to validate the throughput results for a larger scale planning tool, such as MASS. The planned throughput of a particular base can be tested in the two models to determine if the airfield can handle the specified daily flow of air traffic. In addition, if the airfield is not equipped to handle the desired throughput, sensitivity analysis can be performed to determine what additional resources would be required in order to accommodate it.

To use ACE as a validation tool, simply use the resources of the airfield as the input parameters for ACE, along with the types of aircraft to be used, the number of each type aircraft, and the desired mission parameters (amount of fuel required and cargo to be processed). ACE can then be used to compute whether or not the airfield's resources are capable of supporting the desired missions, and highlight any additional capability to support each type of aircraft. This can be compared to the MASS model to determine

whether or not the airfield can actually support the flow of aircraft that are routed through it daily in the MASS simulation run.

The limitations of ACE, however, once again come into play. Recall that in ACE, every aircraft within each mission must have identical input parameters, including aircraft type, configuration, amount of fuel required, and number of passengers and pallets to be off-loaded and on-loaded. Also, only six different mission types can be entered, and ACE evaluates each mission individually before proceeding to the next mission. These limitations significantly reduce the capability of ACE to accommodate real world data from MASS.

BRACE can be used as a validation tool for MASS in a similar way, however with better success. BRACE has the added capability of using an output file from MASS to generate the aircraft arrival stream and specify servicing requirements. If an applicable MASS file is not available, the data can still be entered manually along with a mean interarrival time, and BRACE will generate the aircraft arrival stream itself. Using the BRACE simulation, we can then determine the average number of aircraft that will be processed each day given the input level of resources and aircraft arrival rate. BRACE will also tell us what average delay times, system times, and number of aircraft diverts to expect given these resources and arrival rate. This is valuable information that we do not get from ACE. The airfield may indeed have the capability to support the aircraft flow rate dictated by MASS; however, if delay times, system times, and/or aircraft diverts are excessive, this flow rate may not be acceptable.

Ramstein AB Validation Exercise

An output file from MASS was obtained from HQ AMC/XPY representing an aircraft arrival flow through Ramstein AB during a real world contingency. In addition, BRACE input files were obtained representing the actual resources available. In the BRACE simulation run, Ramstein AB was easily able to accommodate the planned aircraft throughput. The summary output file for this simulation run is included in Appendix H.

Chapter 6

Results

Data Generation

To further explore the effect of certain input parameters on airfield capacity, data sets were generated using both ACE and BRACE. To generate the data, five input parameters were selected to vary in ACE: aircraft type, number of parking spots, number of hydrant-service vehicles, number of k-loaders, and type of k-loaders. The same five input parameters were varied in BRACE, with the exception of one. For reasons discussed previously, fuel trucks were used instead of hydrant service vehicles, with two fuel trucks used in BRACE for every one HSV in ACE. Each of these input parameters was varied at two levels, with the exception of k-loader type, where three levels were required. The experimental design used to generate the data for both models was a $2^4 * 3^1$ full factorial design, requiring 48 runs.

The input parameters and the ranges used are shown in the tables below:

Table3: Input Variables Varied in ACE

Variable	Range
Aircraft Type	C-5, C17
# Parking Spots	6, 12
# HSV's.	2, 4
# k-loaders	2, 6
Type k-loader	25k, 40k, 60k

Table 4: Input Variables Varied in BRACE

Variable	Range
Aircraft Type	C-5, C17
# Parking Spots	6, 12
# Fuel Trucks	4, 8
# k-loaders	2, 6
Type k-loader	25k, 40k, 60k

In addition, six distinct center points were generated, one for each aircraft type and k-loader type at the center of the range of the remaining parameters: nine parking spots, four k-loaders, three HSVs (for ACE), and six fuel trucks (for BRACE).

The data set for the ACE model results is included in Appendix A. The table includes columns for average ground time, loading capacity, fueling capacity, and ramp capacity. The overall airfield capacity given is the minimum of the three individual resource capacities.

The data set for the BRACE model results is included in Appendix B. The BRACE airfield capacity was calculated using the method described in the previous chapter. For the majority of the data points, several runs were made while varying the aircraft arrival rate to determine the maximum capacity for a given set of resources. The table includes only the results for the run where the maximum capacity occurred, with the utilization rates for the k-loaders and fuel trucks also given.

Average aircraft ground time is also included in the table. It is interesting to note that when the number of parking spots is increased from six to twelve, the average ground time increases substantially. With fewer parking spots available, the aircraft wait for the limited resources while still airborne in the holding pattern queue. With more parking spots, more aircraft are able to wait in parking, resulting in longer ground times.

Airfield Calculations from the Model Results

In addition to airfield capacity, the parking MOG, working MOG, and throughput capacity were also computed for each of the runs. The definitions and equations given in

Chapter Two were used for these computations. The results are shown in Appendix C for the ACE model, and Appendix D for the BRACE model.

Parking MOG was very simple to compute. The number of parking spots available to accommodate the type of aircraft in question was included as one of the inputs in the model. This translated directly to parking MOG.

Working MOG was computed as discussed in the previous chapter, using the equation for MOG expressed as a function of airfield capacity and aircraft ground time. Merrill's definition of working MOG was also considered, requiring that the total aircraft ground time be within a planned time interval.

For the results from the ACE model, the average ground times given (2.867 for the C-17 and 4.133 for the C-5), are reasonable, and these were assumed to fall within the desired planned time interval for the aircraft. These ground times were used for the ACE model working MOG computations. The BRACE model results included excessive ground times for many of the runs, since the airfields were deliberately saturated. For example, for one run involving the C-5 aircraft, the average ground time was 26.6 hours. This most likely would not be within anyone's acceptable planned ground time.

To allow the concept of desired planned ground time to remain in the calculations, and to obtain a more conservative estimate of working MOG, the average ground times computed in the ACE model results were used for the BRACE working MOG calculations. It was first determined, however, that aircraft in the BRACE model could be processed within this average time period with a decreased aircraft arrival rate where the majority of the queuing was eliminated.

Throughput capacity was also calculated for each of the runs. Recall that throughput capacity is simply the product of airfield capacity and the maximum amount of cargo that can be carried by each aircraft. In the runs of both models, all aircraft were carrying their maximum palletized cargo loads, with each C-17 carrying 18 pallets and each C-5 carrying 36. At 2.2 tons per pallet, this translated to 39.6 tons, and 79.2 tons, respectively.

ACE Response Surface Results

From the data sets, a response surface was constructed to predict airfield capacity based on the values of the five input parameters. SAS JMP© was used for the regression analysis. Forward stepwise regression was conducted initially on all first and second order terms and all two level interactions to determine which variables to include in the model. The response surface was then constructed using standard least squares. The output results are shown below, to include the summary of fit and parameter estimates.

Table 5: ACE JMP Output Results

Response: Capacity

Summary of Fit

RSquare	0.939772
RSquare Adj	0.927452
Root Mean Square Error	4.132687
Mean of Response	31.42593
Observations (or Sum Wgts)	54

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-43.34585	16.62087	-2.61	0.0124
A/C	17.074074	1.124775	15.18	<.0001
parking	-2.333333	0.743969	-3.14	0.0030
fuel	46.875	10.96656	4.27	0.0001
parking*fuel	0.5833333	0.198834	2.93	0.0053
k-ldrs	-4.625	1.300046	-3.56	0.0009
parking*k-ldrs	0.2916667	0.099417	2.93	0.0053
fuel*k-ldrs	2.3125	0.298251	7.75	<.0001
k-ldr size	0.1114114	0.039226	2.84	0.0068
fuel*fuel	-9.458333	1.789506	-5.29	<.0001

The effect tests and analysis of variance tables are included in Appendix E.

As can be seen from the results, the R^2 of 0.94 and root mean square error of 4.13 are both very good, and the model appears to be a good fit. Examining the plot of the residuals against the predicted capacity (included in Appendix E), the residuals appear to have a constant variance. Examining a normal quantile plot of the residuals (included in Appendix E), they appear to be normally distributed. The Shapiro-Wilk Test for normality (also included in Appendix E) confirms this, with a high p-value of 0.8175.

The estimates of the parameter values are not easy to interpret. The aircraft type has a fairly large coefficient estimate, since obviously, the airfield capacity increases when C-17s are used in the simulation as opposed to C-5s. However, the coefficient estimates for the number of parking spots and the number of k-loaders are both negative, seeming to imply that airfield capacity decreases when there are additional parking spots and k-loaders available. This is obviously not the case. Upon further inspection, it can be seen that both terms have positive interaction terms that compensate for the negative values. The largest coefficient estimate is for the number of fueling units available, which is compensated for by a negative value for the second order term of fueling units, which was the only quadratic term included in the model.

To validate the regression model, twelve additional design points were generated using previously unused values of the five response variables. Airfield capacity estimates were generated for each point using ACE. Predicted capacities were also generated for each design point using the regression model above, as well as 95% confidence intervals for the prediction of new observations. These are included in Appendix E, under ACE Response Surface Results, with the twelve additional design points being the last twelve

points in the table. As can be seen, the ACE generated airfield capacities for all twelve points fall within the 95% confidence prediction intervals.

The root mean square error (MSE) for these twelve points was calculated using the formula below, with n = 12:

$$\text{Root MSE} = \sqrt{\frac{\sum_{i=1}^{n} (y_i - y_{i(hat)})^2}{n}}$$

where y_i is the airfield capacity as determined by ACE, and $y_{i(hat)}$ is the fitted value as determined by the regression equation. The computed root MSE for the twelve points is fairly low, at 4.21.

BRACE Response Surface Results

A response surface was also constructed for the data from the BRACE model. Once again, SAS JMP© was utilized for the regression analysis, and forward stepwise regression was used to select the variables to include in the model. Once again, all first and second order terms and all two level interactions were entered into the stepwise regression, and standard least squares was used to construct the response surface. The output results are shown at the top of the next page, to include the summary of fit and parameter estimates. The effect tests and analysis of variance tables are included in Appendix F.

As can be seen from the results, the R^2 of 0.967 and root mean square error of 2.11 are both very good, and the model appears to be a good fit. Examining the plot of the residuals against the predicted capacity (included in Appendix F), the variance of the

residuals appears to be fairly constant. From the normal quantile plot of the residuals (included in Appendix F), they appear to be normally distributed.

Table 6: BRACE JMP Output Results

Response: Capacity

Summary of Fit

RSquare	0.966917
RSquare Adj	0.964216
Root Mean Square Error	2.109957
Mean of Response	22.72037
Observations (or Sum Wgts)	54

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3137888	1.266168	1.83	0.0737
A/C	5.4935185	1.346753	4.08	0.0002
# k ldrs	2.04375	0.215347	9.49	<.0001
A/C*# k ldrs	2.7479167	0.304546	9.02	<.0001
type ldr	0.0957357	0.020027	4.78	<.0001

From the Shapiro-Wilk Test for normality (also included in Appendix F), the p-value is 0.5810, and we can conclude that the residuals are normally distributed.

The parameter estimates in this case are fairly easy to interpret. There are only four variables included in the model, with all having positive coefficients. Although the coefficient for the k-loader type appears small when compared to the other parameters, it must be realized that this coefficient is multiplied by the weight capacity of the k-loader used (25, 40 or 60), so the effect of the resulting number is on the same scale as the other parameters.

When examining the parameter estimates, one of the first things we notice is that the number of fuel trucks and the number of parking spots are not included in the model. It appears that the number of these resources used in the BRACE runs had relatively no impact on airfield capacity. This is not to say that fuel trucks and parking spots have no bearing on airfield capacity in BRACE. In the results from our

experimental runs, the fuel trucks and parking spots were seldom the constraining resource. If a smaller number of these resources had been used, these variables would have been included in the model.

Once again, to validate the regression model, twelve additional design points were generated using previously unused values of the five response variables. Airfield capacity estimates were generated using BRACE, and predicted capacities were generated using the regression model above. 95% confidence intervals for the prediction of new observations were also generated. These are included in Appendix F, under BRACE Response Surface Results, with the twelve additional design points being the last twelve points in the table. As can be seen, the BRACE generated airfield capacities fall within the 95% confidence prediction intervals for eleven out of the twelve points, or 91.6% of the time. The root mean square error (MSE) for these twelve points, using the formula given in the previous section, is very low, at 1.74.

Differences Between the ACE and BRACE Results

Of the 54 design points generated, the ACE airfield capacity estimates exceeded the BRACE estimates in 49 of the 54 cases. The mean of the airfield capacities from the ACE runs was 31.43, with a variance of 235.42. The mean of the capacities from the BRACE runs was 22.68, with a variance of 123.05. The mean difference between the two models was 8.75, and the maximum difference was 30.4.

A 95% confidence interval was constructed on the difference between the two means. The interval (3.7, 13.8) does not include zero, so we can conclude that there is a statistical difference between the airfield capacity means of the two models.

Next, a response surface was constructed on the difference between the capacities of the two models as a function of the input variables. Once again, SAS JMP© was utilized for the regression analysis, and forward stepwise regression was used to select the variables to include in the model. All first and second order terms and all two level interactions were entered into the stepwise regression, and standard least squares was used to construct the response surface. The output results are shown below, to include the summary of fit and parameter estimates. The data table used, the effect tests and analysis of variance tables are included in Appendix G.

Table 7: Model Differences JMP Output Results

Summary of Fit

Rsquare	0.768865
Rsquare Adj	0.749997
Root Mean Square Error	4.160594
Mean of Response	8.748148
Observations (or Sum Wgts)	54

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-43.85833	15.21606	-2.88	0.0058
fuel	40.020833	10.89263	3.67	0.0006
k-ldrs	-5.425	0.949521	-5.71	<.0001
fuel*k-ldrs	2.3229167	0.300265	7.74	<.0001
fuel*fuel	-7.445833	1.80159	-4.13	0.0001

The R^2 of 0.77 and root mean square error of 4.16 are not quite as good as the previous regression models. Examining the plot of the residuals against the predicted capacity (included in Appendix G), the variance of the residuals is not constant. From the normal quantile plot of the residuals (included in Appendix G), we can see that they do not appear to be normally distributed. The Shapiro-Wilk test confirms this, with a p-value of 0.0154, and we can conclude that the residuals are not normally distributed.

Although the residuals violate the assumptions of a regression model, we can still draw conclusions based on the results. Examining the parameter estimates, we can see

that only two first-order terms are included, the number of fuel resources and the number of k-loaders. These are the two factors that contribute the most significantly to differences between the results of the models, with fuel resources having the largest impact of the two. Since we are using different fuel resources in the two different models, it is not surprising that this is the source of the greatest difference between their results.

Potential Usefulness of the Regression Models

The response surfaces constructed for the ACE and BRACE models above are only valid in the range of input parameters used in each of the regression models. This severely limits the usefulness of the actual regression models constructed above. However, they do demonstrate that regression can be utilized to provide estimates for the airfield capacity of either model over a given range of parameters.

This could prove useful in constructing regression models based on ACE or BRACE centered at the level of resources available at a particular airfield. These regression models could be used to provide quick, real time estimates of airfield capacity as the resource availability at the airfield fluctuates within a given range. They could also be used in sensitivity analysis to determine the benefit of additional resources to the capacity of the airfield.

Chapter 7

Conclusions and Recommendations

As long as our nation continues to maintain a worldwide influence, our military will continue to be called upon to operate at locations throughout the globe, and to move cargo and personnel from one point to another. Our ability to do this is hinged on the capability of the airfields that we operate out of to support the required flow of aircraft.

Currently, throughout Air Mobility Command, there is no one command-wide accepted definition for terms such as airfield capacity and MOG. There is also no uniformly accepted method of estimating or measuring them at an airfield. Obviously, it would be beneficial to all parties involved if standardized definitions were developed for these metrics, as well as methods of estimating and measuring them. The definitions posed in Chapter Two of this report constitute a step in this direction.

It is crucial to mobility planners to have a means to estimate the capacity of the airfields that our military operate out of. A model that accurately estimates this capacity could be an invaluable tool in this planning process. This need was acknowledged when, in early 1994, the Office of the Secretary of Defense commissioned RAND to develop a method that improved on the traditional maximum on ground (MOG) measure of airfield capacity. The result was the ACE model. Around the same time period, HQ AMC/XPY began work, in cooperation with Washington University, St. Louis, on a simulation model that could be used to estimate an airfield's capacity. This resulted in the BRACE model.

However, the need for a tool to assist in estimating airfield capacity is currently not being filled by either ACE or BRACE. At this time, both models have numerous problems and shortcomings that limit their effectiveness for routine mobility analysis. This is not to say, however, that the use of the models can bring no benefits. As long as the limitations of the models are recognized and dealt with, their use can enable a great deal to be learned concerning the capacities of airfields and their resource requirements.

Recommendations

Air Mobility Command currently has no valid method of estimating the capacity of an airfield, or its MOG values. There is no question that one is needed. The ACE and BRACE models, in spite of their many problems, appear to offer the greatest potential.

It appears that many of the errors in both models could be corrected through relatively minor changes in the coding of the models. Correcting the divert error in BRACE, for example, should be relatively straightforward for someone familiar with MODSIM II and the model's code. However, with its 20000 lines of code, making any changes in BRACE could prove a daunting task for anyone who lacks this familiarity.

Correcting the errors and making improvements to the models could be a very worthwhile subject for future research efforts. Improvements could also be made to overcome some of the models limitations, or at least to lessen their impact. The length of time required to run BRACE, for example, could be substantially reduced by allowing the program to run truly apart from the simulation animation, and additional stochastic parameters could be built into both models to increase their validity.

Even with major changes, however, it is likely that some of the limitations of the models would still exist. However, they could still provide results that are vastly superior to what is available today. An alternative option would be to develop an entire new model for estimating airfield capacity. However, this could pose a much greater requirement for time and resources, and it is likely that a new model could contain some of the same problems and limitations as the two models evaluated here.

It is clear that a tool is needed to assist mobility planners in estimating the capacity of the airfields from which we operate. In the absence of a better method, ACE and BRACE appear to be the logical choices. With the changes and improvements described above, ACE and BRACE could someday become the valuable analytical tools they were envisioned to be.

Appendix A

ACE Data Table and Model Results

Type A/C	Parking spots	# HSV's	# k ldrs	Type k ldrs	Ground time	Loading capacity	Fueling capacity	Ramp capacity	Airfield capacity
C-17	12	2	2	25	2.867	24	38	100	24
C-17	12	2	6	25	2.867	72	38	100	38
C-17	12	2	2	40	2.867	27	38	100	27
C-17	12	2	6	40	2.867	72	38	100	38
C-17	12	2	2	60	2.867	31	38	100	31
C-17	12	2	6	60	2.867	72	38	100	38
C-17	12	4	2	25	2.867	24	75	100	24
C-17	12	4	6	25	2.867	72	75	100	72
C-17	12	4	2	40	2.867	27	75	100	27
C-17	12	4	6	40	2.867	72	75	100	72
C-17	12	4	2	60	2.867	31	75	100	31
C-17	12	4	6	60	2.867	72	75	100	72
C-17	6	2	2	25	2.867	24	38	50	24
C-17	6	2	6	25	2.867	72	38	50	38
C-17	6	2	2	40	2.867	27	38	50	27
C-17	6	2	6	40	2.867	72	38	50	38
C-17	6	2	2	60	2.867	31	38	50	31
C-17	6	2	6	60	2.867	72	38	50	38
C-17	6	4	2	25	2.867	24	75	50	24
C-17	6	4	6	25	2.867	72	75	50	50
C-17	6	4	2	40	2.867	27	75	50	27
C-17	6	4	6	40	2.867	72	75	50	50
C-17	6	4	2	60	2.867	31	75	50	31
C-17	6	4	6	60	2.867	72	75	50	50
C-5	12	2	2	25	4.133	12	24	70	12
C-5	12	2	6	25	4.133	36	24	70	24
C-5	12	2	2	40	4.133	13	24	70	13
C-5	12	2	6	40	4.133	40	24	70	24
C-5	12	2	2	60	4.133	16	24	70	16
C-5	12	2	6	60	4.133	47	24	70	24
C-5	12	4	2	25	4.133	12	47	70	12
C-5	12	4	6	25	4.133	36	47	70	36
C-5	12	4	2	40	4.133	13	47	70	13
C-5	12	4	6	40	4.133	40	47	70	40
C-5	12	4	2	60	4.133	16	47	70	16
C-5	12	4	6	60	4.133	47	47	70	47
C-5	6	2	2	25	4.133	12	24	35	12
C-5	6	2	6	25	4.133	36	24	35	24
C-5	6	2	2	40	4.133	13	24	35	13
C-5	6	2	6	40	4.133	40	24	35	24
C-5	6	2	2	60	4.133	16	24	35	16
C-5	6	2	6	60	4.133	47	24	35	24
C-5	6	4	2	25	4.133	12	47	35	12

C-5	6	4	6	25	4.133	36	47	35	35
C-5	6	4	2	40	4.133	13	47	35	13
C-5	6	4	6	40	4.133	40	47	35	35
C-5	6	4	2	60	4.133	16	47	35	16
C-5	6	4	6	60	4.133	47	47	35	35
C-17	9	3	4	25	2.867	48	56	75	48
C-17	9	3	4	40	2.867	53	56	75	53
C-17	9	3	4	60	2.867	62	56	75	56
C-5	9	3	4	25	4.133	24	36	52	24
C-5	9	3	4	40	4.133	27	36	52	27
C-5	9	3	4	60	4.133	31	36	52	31

Appendix B

BRACE Data Table and Model Results

Type A/C	Parking Spots	# Fuel Trucks	# k ldrs	Type k ldrs	Ground Time	Airfield Capacity	k Ldr Util	Fuel Trk Util
C-17	12	4	2	25	13.79	17.7	2	1.7
C-17	12	4	6	25	6.03	41	6	3.8
C-17	12	4	2	40	11.32	20.4	2	2
C-17	12	4	6	40	5.83	42.3	5.2	4
C-17	12	4	2	60	5.22	25	2	2.4
C-17	12	4	6	60	5.83	42.3	4.7	4
C-17	12	8	2	25	14.88	17.7	2	1.7
C-17	12	8	6	25	6.43	41.6	6	6.1
C-17	12	8	2	40	11.77	20.4	2	2
C-17	12	8	6	40	6.47	42.3	5.1	8
C-17	12	8	2	60	10.76	25	2	2.4
C-17	12	8	6	60	6.47	42.3	4.7	8
C-17	6	4	2	25	7.39	17.7	2	1.7
C-17	6	4	6	25	3.61	38.4	5.2	3.4
C-17	6	4	2	40	6.4	20.3	2	1.9
C-17	6	4	6	40	3.64	38.2	4.7	3.5
C-17	6	4	2	60	5.27	24.4	2	2.3
C-17	6	4	6	60	3.71	37.9	4.2	3.5
C-17	6	8	2	25	7.08	17.7	2	1.7
C-17	6	8	6	25	3.22	37.6	5.3	3.4
C-17	6	8	2	40	7.08	20.3	2	1.9
C-17	6	8	6	40	3.12	37.2	4.7	5
C-17	6	8	2	60	5.39	24.4	2	2.3
C-17	6	8	6	60	3.25	37.6	4.2	4.6
C-5	12	4	2	25	26.61	8.9	2	1.8
C-5	12	4	6	25	13.8	20.1	6	3.9
C-5	12	4	2	40	19.95	10.5	2	2.2
C-5	12	4	6	40	12.67	21	5.2	4
C-5	12	4	2	60	19.25	12.2	2	2.6
C-5	12	4	6	60	12.37	21	4.7	4
C-5	12	8	2	25	26.85	8.9	2	1.8
C-5	12	8	6	25	13.95	19.7	6	7.2
C-5	12	8	2	40	20.02	10.6	2	2.2
C-5	12	8	6	40	12.99	20.9	5.3	7.7
C-5	12	8	2	60	19.15	12.3	2	2.5
C-5	12	8	6	60	12.98	20.7	4.6	8
C-5	6	4	2	25	14.97	8.9	2	1.8
C-5	6	4	6	25	8.55	15.1	4.7	2.9
C-5	6	4	2	40	13.1	10.3	1.9	2
C-5	6	4	6	40	7.83	17	4.3	3.2
C-5	6	4	2	60	11.09	11.6	1.9	2.3
C-5	6	4	6	60	7.83	17	3.8	3.2
C-5	6	8	2	25	14.96	8.9	2	1.7

C-5	6	8	6	25	8.46	16.1	5.1	3.2
C-5	6	8	2	40	13.02	10.3	2	2
C-5	6	8	6	40	7.99	17.2	3.5	3.1
C-5	6	8	2	60	11.08	11.6	1.8	2.1
C-5	6	8	6	60	7.7	17.3	3.9	4
C-17	9	6	4	25	6.91	29.9	4	2.8
C-17	9	6	4	40	4.54	35.6	3.8	3.4
C-17	9	6	4	60	5.42	38.5	4	3.7
C-5	9	6	4	25	17.7	11.2	4	2.3
C-5	9	6	4	40	13.86	14.5	4	2.8
C-5	9	6	4	60	8.89	17.1	3.6	3.4

Appendix C

Airfield Calculations from ACE Model Results

Type A/C	Park Spots	HSV's	# k ldrs	Type k ldr	Ground time	Airfield Capacity	Parking MOG	Working MOG	Throughput Capacity (tons)
C-17	12	2	2	25	2.867	24	12	2.86	950.4
C-17	12	2	6	25	2.867	38	12	4.54	1504.8
C-17	12	2	2	40	2.867	27	12	3.23	1069.2
C-17	12	2	6	40	2.867	38	12	4.53	1504.8
C-17	12	2	2	60	2.867	31	12	3.70	1227.6
C-17	12	2	6	60	2.867	38	12	4.54	1504.8
C-17	12	4	2	25	2.867	24	12	2.86	950.4
C-17	12	4	6	25	2.867	72	12	8.60	2851.2
C-17	12	4	2	40	2.867	27	12	3.23	1069.2
C-17	12	4	6	40	2.867	72	12	8.59	2851.2
C-17	12	4	2	60	2.867	31	12	3.70	1227.6
C-17	12	4	6	60	2.867	72	12	8.60	2851.2
C-17	6	2	2	25	2.867	24	6	2.86	950.4
C-17	6	2	6	25	2.867	38	6	4.54	1504.8
C-17	6	2	2	40	2.867	27	6	3.23	1069.2
C-17	6	2	6	40	2.867	38	6	4.53	1504.8
C-17	6	2	2	60	2.867	31	6	3.70	1227.6
C-17	6	2	6	60	2.867	38	6	4.54	1504.8
C-17	6	4	2	25	2.867	24	6	2.86	950.4
C-17	6	4	6	25	2.867	50	6	5.97	1980
C-17	6	4	2	40	2.867	27	6	3.23	1069.2
C-17	6	4	6	40	2.867	50	6	5.97	1980
C-17	6	4	2	60	2.867	31	6	3.70	1227.6
C-17	6	4	6	60	2.867	50	6	5.97	1980
C-5	12	2	2	25	4.133	12	12	2.07	950.4
C-5	12	2	6	25	4.133	24	12	4.13	1900.8
C-5	12	2	2	40	4.133	13	12	2.24	1029.6
C-5	12	2	6	40	4.133	24	12	4.13	1900.8
C-5	12	2	2	60	4.133	16	12	2.76	1267.2
C-5	12	2	6	60	4.133	24	12	4.13	1900.8
C-5	12	4	2	25	4.133	12	12	2.07	950.4
C-5	12	4	6	25	4.133	36	12	6.20	2851.2
C-5	12	4	2	40	4.133	13	12	2.24	1029.6
C-5	12	4	6	40	4.133	40	12	6.89	3168
C-5	12	4	2	60	4.133	16	12	2.76	1267.2
C-5	12	4	6	60	4.133	47	12	8.09	3722.4
C-5	6	2	2	25	4.133	12	6	2.07	950.4
C-5	6	2	6	25	4.133	24	6	4.13	1900.8
C-5	6	2	2	40	4.133	13	6	2.24	1029.6
C-5	6	2	6	40	4.133	24	6	4.13	1900.8
C-5	6	2	2	60	4.133	16	6	2.76	1267.2
C-5	6	2	6	60	4.133	24	6	4.13	1900.8
C-5	6	4	2	25	4.133	12	6	2.07	950.4
C-5	6	4	6	25	4.133	35	6	6.0	2772

C-5	6	4	2	40	4.133	13	6	2.24	1029.6
C-5	6	4	6	40	4.133	35	6	6.0	2772
C-5	6	4	2	60	4.133	16	6	2.76	1267.2
C-5	6	4	6	60	4.133	35	6	6.0	2772
C-17	9	3	4	25	2.867	48	9	5.73	3801.6
C-17	9	3	4	40	2.867	53	9	6.33	4197.6
C-17	9	3	4	60	2.867	56	9	6.69	4435.2
C-5	9	3	4	25	4.133	24	9	4.13	1900.8
C-5	9	3	4	40	4.133	27	9	4.65	2138.4
C-5	9	3	4	60	4.133	31	9	5.34	2455.2

Appendix D

Airfield Calculations from BRACE Model Results

Type A/C	Parking Spots	# Fuel Trucks	# k ldrs	Type k ldrs	Desired Grd Time	Airfield Capacity	Parking MOG	Working MOG	Throughput Capacity (tons)
C-17	12	4	2	25	2.867	17.7	12	2.1	700.92
C-17	12	4	6	25	2.867	41	12	4.9	1623.6
C-17	12	4	2	40	2.867	20.4	12	2.4	807.84
C-17	12	4	6	40	2.867	42.3	12	5.1	1675.08
C-17	12	4	2	60	2.867	25	12	3.0	990
C-17	12	4	6	60	2.867	42.3	12	5.1	1675.08
C-17	12	8	2	25	2.867	17.7	12	2.1	700.92
C-17	12	8	6	25	2.867	41.6	12	5.0	1647.36
C-17	12	8	2	40	2.867	20.4	12	2.4	807.84
C-17	12	8	6	40	2.867	42.3	12	5.1	1675.08
C-17	12	8	2	60	2.867	25	12	3.0	990
C-17	12	8	6	60	2.867	42.3	12	5.1	1675.08
C-17	6	4	2	25	2.867	17.7	6	2.1	700.92
C-17	6	4	6	25	2.867	38.4	6	4.6	1520.64
C-17	6	4	2	40	2.867	20.3	6	2.4	803.88
C-17	6	4	6	40	2.867	38.2	6	4.6	1512.72
C-17	6	4	2	60	2.867	24.4	6	2.9	966.24
C-17	6	4	6	60	2.867	37.9	6	4.5	1500.8
C-17	6	8	2	25	2.867	17.7	6	2.1	700.92
C-17	6	8	6	25	2.867	37.6	6	4.5	1488.96
C-17	6	8	2	40	2.867	20.3	6	2.4	803.88
C-17	6	8	6	40	2.867	37.2	6	4.4	1473.12
C-17	6	8	2	60	2.867	24.4	6	2.9	966.24
C-17	6	8	6	60	2.867	37.6	6	4.5	1488.96
C-5	12	4	2	25	4.133	8.9	12	1.5	704.88
C-5	12	4	6	25	4.133	20.1	12	3.5	1591.92
C-5	12	4	2	40	4.133	10.5	12	1.8	831.6
C-5	12	4	6	40	4.133	21	12	3.6	1663.2
C-5	12	4	2	60	4.133	12.2	12	2.1	966.24
C-5	12	4	6	60	4.133	21	12	3.6	1663.2
C-5	12	8	2	25	4.133	8.9	12	1.5	704.88
C-5	12	8	6	25	4.133	19.7	12	3.4	1560.24
C-5	12	8	2	40	4.133	10.6	12	1.8	839.52
C-5	12	8	6	40	4.133	20.9	12	3.6	1655.28
C-5	12	8	2	60	4.133	12.3	12	2.1	974.16
C-5	12	8	6	60	4.133	20.7	12	3.6	1639.44
C-5	6	4	2	25	4.133	8.9	6	1.5	704.88
C-5	6	4	6	25	4.133	15.1	6	2.6	1195.92
C-5	6	4	2	40	4.133	10.3	6	1.8	815.76
C-5	6	4	6	40	4.133	17	6	2.9	1346.4
C-5	6	4	2	60	4.133	11.6	6	2.0	918.72
C-5	6	4	6	60	4.133	17	6	2.9	1346.4
C-5	6	8	2	25	4.133	8.9	6	1.5	704.88
C-5	6	8	6	25	4.133	16.1	6	2.8	1275.12

C-5	6	8	2	40	4.133	10.3	6	1.8	815.76
C-5	6	8	6	40	4.133	17.2	6	3.0	1362.24
C-5	6	8	2	60	4.133	11.6	6	2.0	918.72
C-5	6	8	6	60	4.133	17.3	6	3.0	1370.16
C-17	9	6	4	25	2.867	29.9	9	3.6	1184.04
C-17	9	6	4	40	2.867	35.6	9	4.3	1409.76
C-17	9	6	4	60	2.867	38.5	9	4.6	1524.6
C-5	9	6	4	25	4.133	11.2	9	1.9	887.04
C-5	9	6	4	40	4.133	14.5	9	2.5	1148.4
C-5	9	6	4	60	4.133	17.1	9	2.9	1354.32

Appendix E

ACE Response Surface Analysis Results

Type A/C	Parking Spots	Fuel Trucks	# k ldrs	Type k ldr	Airfield Capacity	Residuals	Predicted Capacity	Lower 95% CI	Upper 95% CI
1	12	4	2	25	17.7	-2.084	19.784	15.329	24.239
1	12	4	6	25	41	2.0493	38.951	34.496	43.405
1	12	4	2	40	20.4	-0.82	21.22	16.816	25.624
1	12	4	6	40	42.3	1.9133	40.387	35.982	44.791
1	12	4	2	60	25	1.8652	23.135	18.67	27.6
1	12	4	6	60	42.3	-0.001	42.301	37.836	46.767
1	12	8	2	25	17.7	-2.084	19.784	15.329	24.239
1	12	8	6	25	41.6	2.6493	38.951	34.496	43.405
1	12	8	2	40	20.4	-0.82	21.22	16.816	25.624
1	12	8	6	40	42.3	1.9133	40.387	35.982	44.791
1	12	8	2	60	25	1.8652	23.135	18.67	27.6
1	12	8	6	60	42.3	-0.001	42.301	37.836	46.767
1	6	4	2	25	17.7	-2.084	19.784	15.329	24.239
1	6	4	6	25	38.4	-0.551	38.951	34.496	43.405
1	6	4	2	40	20.3	-0.92	21.22	16.816	25.624
1	6	4	6	40	38.2	-2.187	40.387	35.982	44.791
1	6	4	2	60	24.4	1.2652	23.135	18.67	27.6
1	6	4	6	60	37.9	-4.401	42.301	37.836	46.767
1	6	8	2	25	17.7	-2.084	19.784	15.329	24.239
1	6	8	6	25	37.6	-1.351	38.951	34.496	43.405
1	6	8	2	40	20.3	-0.92	21.22	16.816	25.624
1	6	8	6	40	39.5	-0.887	40.387	35.982	44.791
1	6	8	2	60	24.4	1.2652	23.135	18.67	27.6
1	6	8	6	60	37.6	-4.701	42.301	37.836	46.767
0	12	4	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	12	4	6	25	20.1	3.1303	16.97	12.515	21.424
0	12	4	2	40	10.5	0.2693	10.231	5.8264	14.635
0	12	4	6	40	21	2.5943	18.406	14.001	22.81
0	12	4	2	60	12.2	0.0546	12.145	7.6802	16.611
0	12	4	6	60	21	0.6796	20.32	15.855	24.786
0	12	8	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	12	8	6	25	19.7	2.7303	16.97	12.515	21.424
0	12	8	2	40	10.6	0.3693	10.231	5.8264	14.635
0	12	8	6	40	20.9	2.4943	18.406	14.001	22.81
0	12	8	2	60	12.3	0.1546	12.145	7.6802	16.611
0	12	8	6	60	20.7	0.3796	20.32	15.855	24.786
0	6	4	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	6	4	6	25	15.1	-1.87	16.97	12.515	21.424
0	6	4	2	40	10.3	0.0693	10.231	5.8264	14.635
0	6	4	6	40	17	-1.406	18.406	14.001	22.81
0	6	4	2	60	11.6	-0.545	12.145	7.6802	16.611
0	6	4	6	60	17	-3.32	20.32	15.855	24.786
0	6	8	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	6	8	6	25	16.1	-0.87	16.97	12.515	21.424

0	6	8	2	40	10.3	0.0693	10.231	5.8264	14.635
0	6	8	6	40	17.2	-1.206	18.406	14.001	22.81
0	6	8	2	60	11.6	-0.545	12.145	7.6802	16.611
0	6	8	6	60	17.3	-3.02	20.32	15.855	24.786
1	9	6	4	25	29.9	0.5326	29.367	24.998	33.737
1	9	6	4	40	35.6	4.7966	30.803	26.485	35.122
1	9	6	4	60	38.5	5.7819	32.718	28.338	37.099
0	9	6	4	25	11.2	-1.682	12.882	8.5125	17.252
0	9	6	4	40	14.5	0.1818	14.318	9.9998	18.637
0	9	6	4	60	17.1	0.8671	16.233	11.852	20.613
1	7	7	3	25	22.3	?	24.576	20.185	28.967
1	11	5	5	25	36.7	?	34.159	29.768	38.55
1	8	7	3	40	27.4	?	26.012	21.672	30.352
1	10	5	5	40	40.3	?	35.595	31.255	39.935
1	7	5	3	60	31.8	?	27.926	23.525	32.328
1	11	7	5	60	41.4	?	37.51	33.108	41.912
0	7	7	3	25	9.9	?	10.838	6.4474	15.23
0	11	5	5	25	18.3	?	14.926	10.535	19.317
0	8	7	3	40	11.9	?	12.274	7.9344	16.615
0	10	5	5	40	20.4	?	16.362	12.022	20.702
0	7	5	3	60	15.4	?	14.189	9.7874	18.591
0	11	7	5	60	20.3	?	18.277	13.875	22.679

Regression Analysis

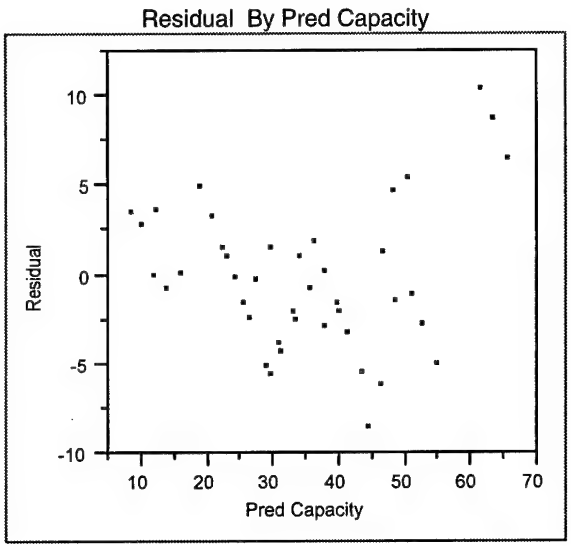
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
A/C	1	1	3935.5741	230.4321	<.0001
parking	1	1	168.0000	9.8366	0.0030
fuel	1	1	312.0377	18.2701	0.0001
parking*fuel	1	1	147.0000	8.6070	0.0053
k-ldrs	1	1	216.1579	12.6563	0.0009
parking*k-ldrs	1	1	147.0000	8.6070	0.0053
fuel*k-ldrs	1	1	1026.7500	60.1173	<.0001
k-ldr size	1	1	137.7788	8.0671	0.0068
fuel*fuel	1	1	477.1204	27.9359	<.0001

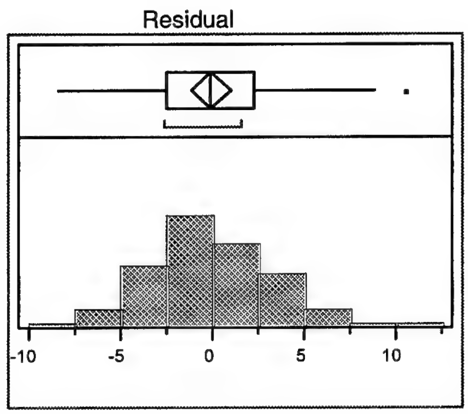
Whole-Model Test
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	11725.723	1302.86	76.2838
Error	44	751.480	17.08	Prob>F
C Total	53	12477.204		<.0001

Residual Analysis



Residual Plot vs. Predicted Capacity



Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.983030	0.8175

Normal Quantile Plot of Residuals and Shapiro-Wilk Test

Appendix F

BRACE Response Surface Analysis Results

Type A/C	Parking Spots	Fuel Trucks	# k ldrs	Type k ldr	Airfield Capacity	Residuals	Predicted Capacity	Lower 95% CI	Upper 95% CI
1	12	4	2	25	17.7	-2.084	19.784	15.329	24.239
1	12	4	6	25	41	2.0493	38.951	34.496	43.405
1	12	4	2	40	20.4	-0.82	21.22	16.816	25.624
1	12	4	6	40	42.3	1.9133	40.387	35.982	44.791
1	12	4	2	60	25	1.8652	23.135	18.67	27.6
1	12	4	6	60	42.3	-0.001	42.301	37.836	46.767
1	12	8	2	25	17.7	-2.084	19.784	15.329	24.239
1	12	8	6	25	41.6	2.6493	38.951	34.496	43.405
1	12	8	2	40	20.4	-0.82	21.22	16.816	25.624
1	12	8	6	40	42.3	1.9133	40.387	35.982	44.791
1	12	8	2	60	25	1.8652	23.135	18.67	27.6
1	12	8	6	60	42.3	-0.001	42.301	37.836	46.767
1	6	4	2	25	17.7	-2.084	19.784	15.329	24.239
1	6	4	6	25	38.4	-0.551	38.951	34.496	43.405
1	6	4	2	40	20.3	-0.92	21.22	16.816	25.624
1	6	4	6	40	38.2	-2.187	40.387	35.982	44.791
1	6	4	2	60	24.4	1.2652	23.135	18.67	27.6
1	6	4	6	60	37.9	-4.401	42.301	37.836	46.767
1	6	8	2	25	17.7	-2.084	19.784	15.329	24.239
1	6	8	6	25	37.6	-1.351	38.951	34.496	43.405
1	6	8	2	40	20.3	-0.92	21.22	16.816	25.624
1	6	8	6	40	39.5	-0.887	40.387	35.982	44.791
1	6	8	2	60	24.4	1.2652	23.135	18.67	27.6
1	6	8	6	60	37.6	-4.701	42.301	37.836	46.767
0	12	4	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	12	4	6	25	20.1	3.1303	16.97	12.515	21.424
0	12	4	2	40	10.5	0.2693	10.231	5.8264	14.635
0	12	4	6	40	21	2.5943	18.406	14.001	22.81
0	12	4	2	60	12.2	0.0546	12.145	7.6802	16.611
0	12	4	6	60	21	0.6796	20.32	15.855	24.786
0	12	8	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	12	8	6	25	19.7	2.7303	16.97	12.515	21.424
0	12	8	2	40	10.6	0.3693	10.231	5.8264	14.635
0	12	8	6	40	20.9	2.4943	18.406	14.001	22.81
0	12	8	2	60	12.3	0.1546	12.145	7.6802	16.611
0	12	8	6	60	20.7	0.3796	20.32	15.855	24.786
0	6	4	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	6	4	6	25	15.1	-1.87	16.97	12.515	21.424
0	6	4	2	40	10.3	0.0693	10.231	5.8264	14.635
0	6	4	6	40	17	-1.406	18.406	14.001	22.81
0	6	4	2	60	11.6	-0.545	12.145	7.6802	16.611
0	6	4	6	60	17	-3.32	20.32	15.855	24.786
0	6	8	2	25	8.9	0.1053	8.7947	4.3401	13.249
0	6	8	6	25	16.1	-0.87	16.97	12.515	21.424
0	6	8	2	40	10.3	0.0693	10.231	5.8264	14.635

0	6	8	6	40	17.2	-1.206	18.406	14.001	22.81
0	6	8	2	60	11.6	-0.545	12.145	7.6802	16.611
0	6	8	6	60	17.3	-3.02	20.32	15.855	24.786
1	9	6	4	25	29.9	0.5326	29.367	24.998	33.737
1	9	6	4	40	35.6	4.7966	30.803	26.485	35.122
1	9	6	4	60	38.5	5.7819	32.718	28.338	37.099
0	9	6	4	25	11.2	-1.682	12.882	8.5125	17.252
0	9	6	4	40	14.5	0.1818	14.318	9.9998	18.637
0	9	6	4	60	17.1	0.8671	16.233	11.852	20.613
1	7	7	3	25	22.3	?	24.576	20.185	28.967
1	11	5	5	25	36.7	?	34.159	29.768	38.55
1	8	7	3	40	27.4	?	26.012	21.672	30.352
1	10	5	5	40	40.3	?	35.595	31.255	39.935
1	7	5	3	60	31.8	?	27.926	23.525	32.328
1	11	7	5	60	41.4	?	37.51	33.108	41.912
0	7	7	3	25	9.9	?	10.838	6.4474	15.23
0	11	5	5	25	18.3	?	14.926	10.535	19.317
0	8	7	3	40	11.9	?	12.274	7.9344	16.615
0	10	5	5	40	20.4	?	16.362	12.022	20.702
0	7	5	3	60	15.4	?	14.189	9.7874	18.591
0	11	7	5	60	20.3	?	18.277	13.875	22.679

Regression Analysis

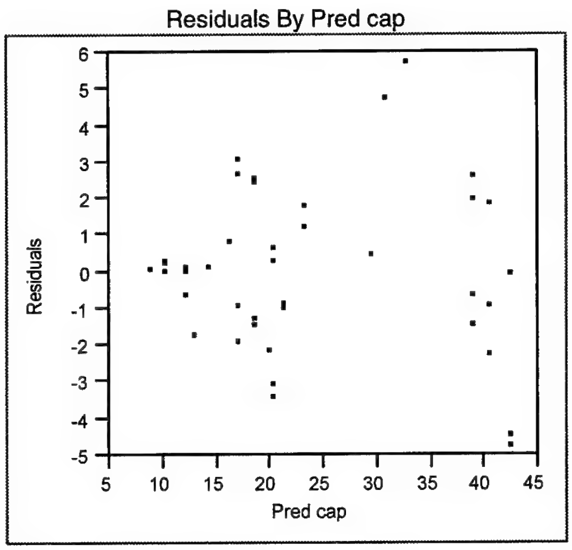
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
A/C	1	1	74.07510	16.6389	0.0002
# k ldrs	1	1	400.98375	90.0699	<.0001
A/C*# k ldrs	1	1	362.45021	81.4144	<.0001
type ldr	1	1	101.73518	22.8520	<.0001

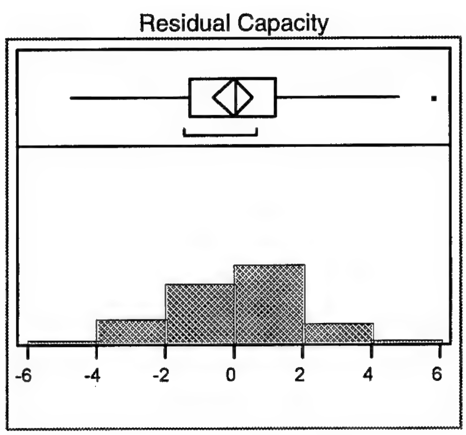
Whole-Model Test
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	6375.6636	1593.92	358.0289
Error	49	218.1440	4.45	Prob>F
C Total	53	6593.8076		<.0001

Residual Analysis



Residual Plot vs. Predicted Capacity



Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.976765	0.5810

Normal Quantile Plot of Residuals and Shapiro-Wilk Test

Appendix G

Model Differences Response Surface Analysis Results

A/C Type	Parking Spots	Fuel Units	# k-loaders	Type k-loader	Capacity Difference	Residuals	Predicted CapDiff
1	12	2	2	25	6.3	1.4583	4.8417
1	12	2	6	25	-3	-4.725	1.725
1	12	2	2	40	6.6	1.7583	4.8417
1	12	2	6	40	-4.3	-6.025	1.725
1	12	2	2	60	6	1.1583	4.8417
1	12	2	6	60	-4.3	-6.025	1.725
1	12	4	2	25	6.3	1.475	4.825
1	12	4	6	25	30.4	10.108	20.292
1	12	4	2	40	6.6	1.775	4.825
1	12	4	6	40	29.7	9.4083	20.292
1	12	4	2	60	6	1.175	4.825
1	12	4	6	60	29.7	9.4083	20.292
1	6	2	2	25	6.3	1.4583	4.8417
1	6	2	6	25	-0.4	-2.125	1.725
1	6	2	2	40	6.7	1.8583	4.8417
1	6	2	6	40	-0.2	-1.925	1.725
1	6	2	2	60	6.6	1.7583	4.8417
1	6	2	6	60	0.1	-1.625	1.725
1	6	4	2	25	6.3	1.475	4.825
1	6	4	6	25	12.4	-7.892	20.292
1	6	4	2	40	6.7	1.875	4.825
1	6	4	6	40	12.8	-7.492	20.292
1	6	4	2	60	6.6	1.775	4.825
1	6	4	6	60	12.4	-7.892	20.292
0	12	2	2	25	3.1	-1.742	4.8417
0	12	2	6	25	3.9	2.175	1.725
0	12	2	2	40	2.5	-2.342	4.8417
0	12	2	6	40	3	1.275	1.725
0	12	2	2	60	3.8	-1.042	4.8417
0	12	2	6	60	3	1.275	1.725
0	12	4	2	25	3.1	-1.725	4.825
0	12	4	6	25	16.3	-3.992	20.292
0	12	4	2	40	2.4	-2.425	4.825
0	12	4	6	40	19.1	-1.192	20.292
0	12	4	2	60	3.7	-1.125	4.825
0	12	4	6	60	26.3	6.0083	20.292
0	6	2	2	25	3.1	-1.742	4.8417
0	6	2	6	25	8.9	7.175	1.725
0	6	2	2	40	2.7	-2.142	4.8417
0	6	2	6	40	7	5.275	1.725
0	6	2	2	60	4.4	-0.442	4.8417
0	6	2	6	60	7	5.275	1.725
0	6	4	2	25	3.1	-1.725	4.825
0	6	4	6	25	18.9	-1.392	20.292

0	6	4	2	40	2.7	-2.125	4.825
0	6	4	6	40	17.8	-2.492	20.292
0	6	4	2	60	4.4	-0.425	4.825
0	6	4	6	60	17.7	-2.592	20.292
1	9	3	4	25	18.1	2.7333	15.367
1	9	3	4	40	17.4	2.0333	15.367
1	9	3	4	60	17.5	2.1333	15.367
0	9	3	4	25	12.8	-2.567	15.367
0	9	3	4	40	12.5	-2.867	15.367
0	9	3	4	60	13.9	-1.467	15.367

Regression Analysis

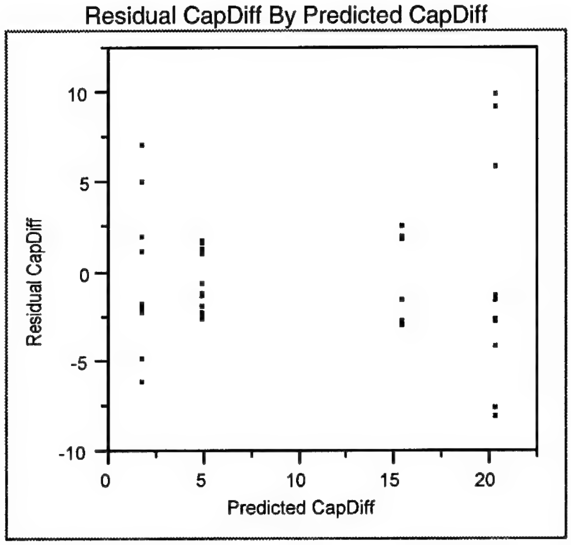
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
fuel	1	1	233.6779	13.4992	0.0006
k-ldrs	1	1	565.0680	32.6430	<.0001
fuel*k-ldrs	1	1	1036.0208	59.8491	<.0001
fuel*fuel	1	1	295.6823	17.0811	0.0001

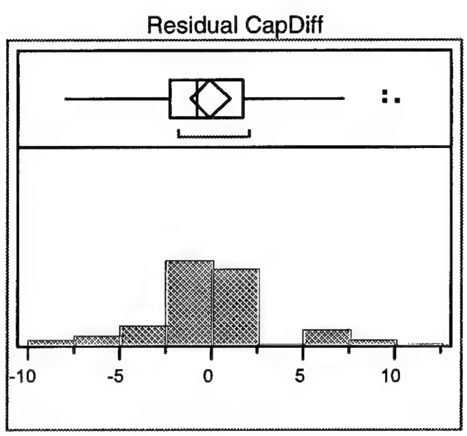
Whole-Model Test
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	2821.5781	705.395	40.7494
Error	49	848.2167	17.311	Prob>F
C Total	53	3669.7948		<.0001

Residual Analysis



Residual Plot vs. Predicted Difference in Capacity



Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.940580	0.0154

Normal Quantile Plot of Residuals and Shapiro-Wilk Test

Appendix H

Ramstein AB Validation Exercise Summary Output File

```
Summary of BRACE simulation Fri Jan 23 14:32:07 1998
BRACE version 1.31; December 18, 1997

 START GLOBAL PARAMETERS
 ( These are the parameters set before execution ).
K to AC Pallet Delay                                        0.03000
K to Dock Pallet Delay                                      0.03000
Palletized Oversize                                         0.20000
Tons Per Pallet                                             2.20000
Tons Per Vehicle                                            2.70000
Dock to Fork Pallet Delay                                   0.02000
K to Fork Pallet Delay                                      0.02000
Position Loader Delay                                       0.02000
Position Loader Delay                                       0.05000
Truck Pump Rate                                           500.00000
Small Truck Capacity                                     4600.00000
Large Truck Capacity                                     5758.00000
Fuel Truck Connect Time                                     0.08330
Fuel Hydrant Connect Time                                   0.04000
Fill Stand Pump Rate                                      650.00000
Fill Stand ConnectTime                                      0.04000
Narrow Body Equivalents                                     2.00000
Landing Duration                                            0.03330
Take Off Duration                                           0.03330
Time Until A/C Divert                                       2.00000

 START AIRFIELD SPECIFIC PARAMETERS

 WideBodyEquivalents                                        0.00000
 NarrowBodyEquivalents                                      2.00000
 Runways                                                          1
25KLoader                                                           2
40KLoader                                                           9
60KLoader                                                           0
NGSLLoader                                                           0
WBEL                                                           2
ForkLift                                                         19
 HighLineDocks                                                   15
 DockSpace                                                       90
 ForkLiftTravel                                             0.05830
 WBELSetupTime                                              0.02000
 KLoader Setup Time                                         0.05000
 PalletPositionsAlbl                                             90
 LargeTrucks                                                      9
 LargeTruckCapacity                                      5758.00000
 SmallTrucks                                                      0
 SmallTruckCapacity                                      4600.00000
 Fill Stands:                                                     2
        Pumps At Fill Stand     1                                 2
        Pumps At Fill Stand     2                                 2
 TruckConnectTime                                           0.08330
 DeicingTrucks                                                    1
```

TruckPumpRate	500.00000
PalletizedOversize	0.20000
TonsPerPallet	2.20000
TonsPerVehicle	2.70000
ACconcMxDelayTime	0.50000
ACnonConcMxDelayTime	0.16000
MeanInterArrivalTime	0.50000
Take Off Duration	0.03330
Landing Duration	0.03330
Open Time	6.00000
Closing Time	22.00000

Ramps:	3

PARKING RAMP NUMBER	1
TotalWideBodySpots	5
TotalNarrowBodySpots	0
TotalNarrowBodyEquivSpots	8
TotalTankerSpots	0
WideBodyHydrantSpots	3
NarrowBodyHydrantSpts	0
NarrowBodyEquivHydrantSpts	8
TankerHydrantSpots	0
TaxiTime	0.12500
KloaderTravel	0.06670
WBELTravelTime	0.06670
TruckTravelTime	0.08330

PARKING RAMP NUMBER	2
TotalWideBodySpots	0
TotalNarrowBodySpots	1
TotalNarrowBodyEquivSpots	0
TotalTankerSpots	0
WideBodyHydrantSpots	0
NarrowBodyHydrantSpts	0
NarrowBodyEquivHydrantSpts	0
TankerHydrantSpots	0
TaxiTime	0.12500
KloaderTravel	0.33330
WBELTravelTime	0.33330
TruckTravelTime	0.33330

PARKING RAMP NUMBER	3
TotalWideBodySpots	1
TotalNarrowBodySpots	0
TotalNarrowBodyEquivSpots	0
TotalTankerSpots	0
WideBodyHydrantSpots	0
NarrowBodyHydrantSpts	0
NarrowBodyEquivHydrantSpts	0
TankerHydrantSpots	0
TaxiTime	0.12500
KloaderTravel	0.33330

WBELTravelTime	0.33330
TruckTravelTime	0.33330

Pump Houses:		1
Max Active Hydrants, House	1	5

Laterals:	3

LATERAL NUMBER	PH 1- 1	
Maximum Active Hydrants		2
Hydrant Pump Rate		550.00000
LATERAL NUMBER	PH 1- 2	
Maximum Active Hydrants		2
Hydrant Pump Rate		550.00000
LATERAL NUMBER	PH 1- 3	
Maximum Active Hydrants		2
Hydrant Pump Rate		550.00000

RESULTS OF THIS SIMULATION START HERE

Airfield Random Number Seed: 6
Aircraft Random Number Seed: 4
Queue Statistics (NeedLoaderQ, etc.) NOT reset during simulation.

DATA DESCRIPTION	VALUE	FRACTION
Total Time of Simulation:	1242.70	
Total Seconds Reqd to Simulate:	253.00	
Statistics gathering started day	1	
Total Time Statistics Gathered:	1242.70	
Average A/C System Time:	4.7302	
Total Aircraft Processed:	1214	
Total Aircraft Delayed Landing	63	0.05189456
Average Delay per Late Landing	0.07344	0.00381099
Total Diverted A/C:	0	0.00000000
Total Late Departing Aircraft:	335	0.27594728
Total Missed Desired Cushion:	114	0.09390445
Average Delay Time per Late A/C	8.01026	
Tower Controlled Delays	0	0.00000000
Average Delay For KLoaders	0.00000000	
Total Hazardous A/C:	53	0.04365733
Total Pallets Offloaded:	5978	0.44137626
Total Pallets Onloaded:	7566	0.55862374
Total Pallets Processed:	13544	1.00000000

Total PAX Processed:		0
Total Outsize Onloaded:	0.00000000	0.00000
Total Outsize Offloaded:	0.00000000	0.00000
Total Oversize Onloaded:	0.00000000	0.00000
Total Oversize Offloaded:	0.00000000	0.00000
Total Bulk Offloaded:	0.42217514	11956.00000
Total Bulk Onloaded:	0.57782486	16364.00000
Total Cargo Processed:	1.00000000	28320.00000
Total Fuel By Truck:	0.09522106	1871093.75000
Total Fuel By Hydrant:	0.90477894	17778906.25000
Total Fuel Transfered:	0.99725191	19596000.00000
Total Fuel:	1.00000000	19650000.00000

BRACE Simulation written by Travis Cusick
travis@rodin.wustl.edu
2103 Prather
St. Louis, MO 63139
314-647-4261

Bibliography

Brigantic, Robert T. Plans Division, HQ Air Mobility Command. Personal Correspondence. 22 October 1998.

Brigantic, Robert T. Plans Division, HQ Air Mobility Command. Personal Correspondence. 17 February 1999.

Cusick, Travis. "BRACE Simulation Overview." Excerpt from unpublished article, 4 pages. WWWeb, http://rodin.wustl.edu/~travis/service.html. 29 July 1998

Cusick, Travis. "Base Resources and Capabilities Estimator (BRACE v1.0) User's Manual." 10 April 1997.

HQ Air Mobility Command, Plans Division. "The Algebra of Airlift." Presentation. Scott AFB, IL.

Merrill, David L. Plans Division, HQ Air Mobility Command. "Discussion of MOG." Scott AFB, IL. June 1994.

Merrill, David L. Plans Division, HQ Air Mobility Command. "Ute Rate is Not a Good Measure of Aircraft Effectiveness." Scott AFB, IL. December 1996.

Merrill, David L. and Pete Szabo. Plans Division, HQ Air Mobility Command. "The Mobility Paradox." A Presentation for the 62nd Military Operations Research Society Symposium. Scott AFB, IL.

Morrison, Marshall T. Estimating Airfield Capacity for AMC Operations. MAM Graduate Research Project, AFIT/GMO/LAC/96N-10. School of Logistics and Acquisition Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH. November 1996.

Ross, Sheldon M. Introduction to Probability Models, 6th Edition, Academic Press, San Diego, 1997.

Rushing, W. Heath. Modeling and Analyzing the Effect of Ground Refueling Capacity on Airfield Throughput, Master's thesis, AFIT/GOR/ENS/97M-19. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH. March 1997.

Schubert, Kim. Plans Division, HQ Air Mobility Command. "Base Resources and Capabilities Estimator (BRACE)." Presentation. Scott AFB, IL. 23 April 1996, 15 pages.

Smith, Ronny C. "Station Capability." Airlift: 14-16 (Winter 1985)

Stucker, James P., Ruth T. Berg, and others. Understanding Airfield Capacity For Airlift Operations. Santa Monica, CA: RAND's Project Air Force and the National Defense Research Institute. 1998.

Stucker, James P. "Read Me file." Excerpt from unpublished article, 1 page. WWWeb, http://www.rand.org/publications/MR/MR700/ACE/readme.html. 1 November 1998.

Suzuki, Laura R.C. Plans Division, HQ Air Mobility Command. Personal Correspondence. 16 December 1998.

Vita

David W. Williams was born on 20 January 1963 in Lincoln, Nebraska. He graduated from Del City High School in 1981, and entered undergraduate studies at the United States Air Force Academy, Colorado Springs, Colorado. He graduated with a Bachelors of Science degree in Electrical Engineering in 1985.

After completing Undergraduate Pilot Training at Vance AFB, Oklahoma, his first assignment was flying KC-135A aircraft at Fairchild AFB, Washington. After upgrading to aircraft commander, he was transferred to Minot AFB, North Dakota. During this time, he flew many combat support missions as part of Operations Desert Shield and Desert Storm in Saudi Arabia.

In December 1993, Major Williams was selected to become an instructor pilot and flight examiner at the KC-135 schoolhouse at Castle AFB, California, which was moved to Altus AFB, Oklahoma in 1995. While at Altus, he completed his Masters Degree in Aviation Science from Embry-Riddle Aeronautical University, in addition to Air Command and Staff College. In August 1997, he was assigned to the Air Force Institute of Technology, Wright-Patterson AFB, Ohio, to pursue a master's degree in Operations Analysis.

Permanent Address: 4724 Tempo Drive
Del City, OK 73115

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1999	Master's Thesis

4. TITLE AND SUBTITLE
AN EVALUATION AND COMPARISON OF THE ACE AND BRACE AIRFIELD MODELS

5. FUNDING NUMBERS

6. AUTHOR(S)
David W. Williams, Major, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
2950 P Street
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GOA/ENS/99M-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
HQ AMC/XPY
402 Scott Drive
Scott AFB, IL 62225

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Airfields are a critical aspect of our military's ability to project power or respond to crises throughout the world. It is crucial that mobility planners have an effective means to estimate the capacity of these airfields. The objective of this research is to examine common mobility metrics and evaluate existing means of measuring them. Currently, Air Mobility Command has two models, the Airfield Capacity Estimator (ACE) and the Base Resource and Capabilities Estimator (BRACE), that were designed to estimate the resource requirements and capacities of an airfield. This study offers a critical evaluation and comparison of the two models. Discrepancies of the models are highlighted, as well as possible improvements. Additional possible uses are also demonstrated, including a method in which the two models can be used together to enhance their overall results and increase the user's knowledge of an airfield's capabilities and limitations.

14. SUBJECT TERMS
Landing fields, airfield capacity, maximum on ground (MOG), throughput, simulation models, mathematical models

15. NUMBER OF PAGES
92

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL